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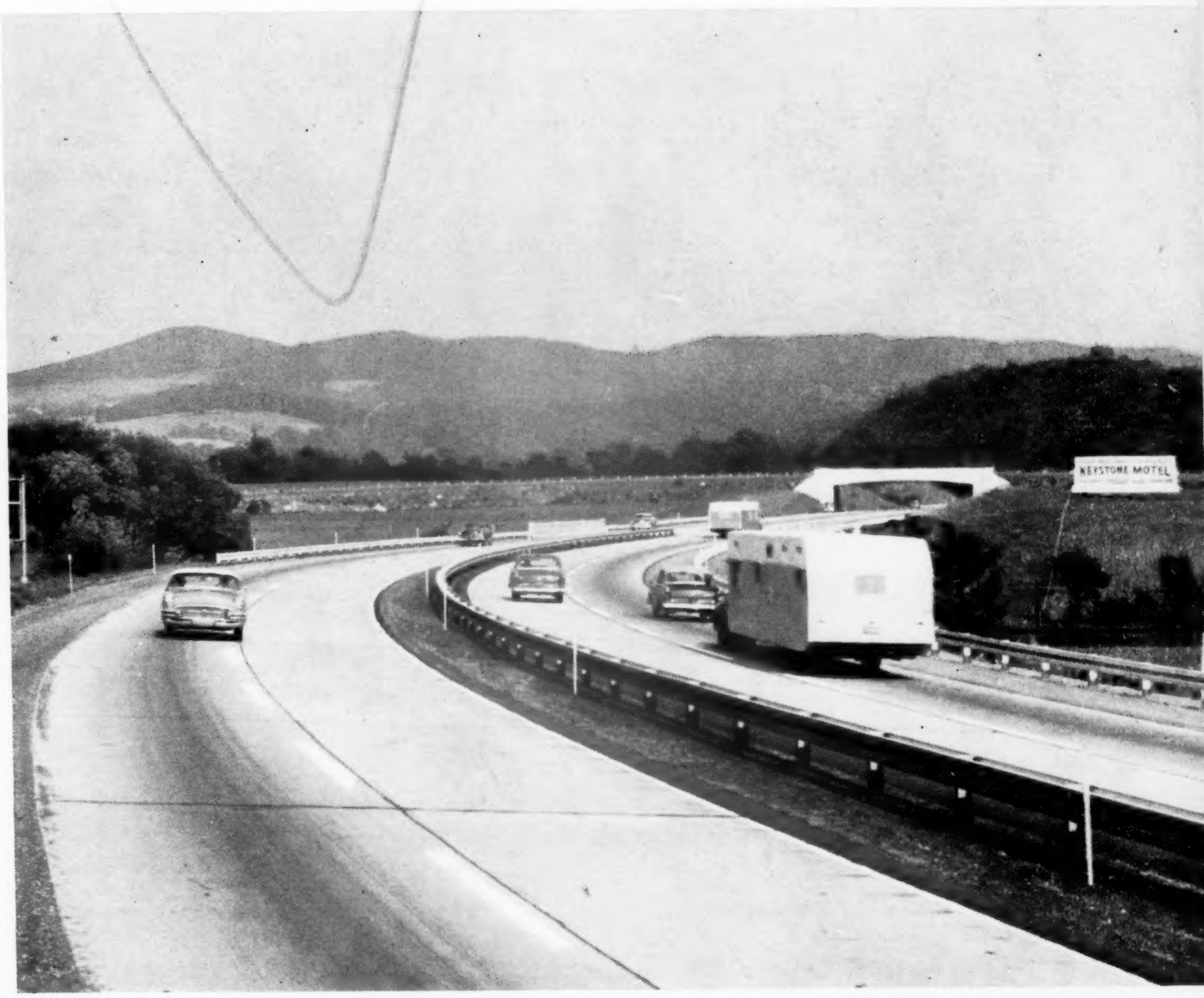

In this issue: Traffic studies of the Maine and Pennsylvania Turnpikes
(Pennsylvania Turnpike between Gettysburg Pike and Harrisburg-West Shore interchanges)

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IN THIS ISSUE

U. S. DEPARTMENT OF COMMERCE
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BUREAU OF PUBLIC ROADS
CHARLES D. CURTISS, Commissioner

Pennsylvania Turnpike Traffic Analysis

BY THE HIGHWAY TRANSPORT RESEARCH BRANCH
BUREAU OF PUBLIC ROADS

Reported by DANIEL O'FLAHERTY
Head, Traffic and Travel Studies Unit

Information regarding turnpike usage was collected at roadside-interview stations on the highways east of Harrisburg and west of Philadelphia during June, July, and August of 1950 before construction of the eastern extension of the Pennsylvania Turnpike, and on the same highways and the turnpike in 1952 after its construction.

Traffic diversion to the toll road was much greater for passenger cars than for commercial vehicles, except in the mountainous areas where the type of vehicle or purpose of trip made little difference.

It was found that a much greater increase in traffic in the vicinity and general direction of the turnpike resulted after its opening than elsewhere in the State, indicating that this facility generated a considerable amount of new traffic.

The travel-time ratio and time saved or lost were found to be good measures for determining the amount of traffic diverted from adjacent highways. Traffic used the toll road if time could be saved, even though the distance was increased; hence the greater the time saving, the greater the usage. Only a small proportion of traffic losing both time and distance used the toll road.

The toll-road usage curves differ from similar curves established for free limited-access highways in metropolitan areas. It was found that the smaller the time or distance saved, the greater the difference between such curves. Traffic diverted to the Pennsylvania Turnpike was between two-thirds and three-fourths of that which would have been assigned from curves developed for free limited-access highways.

Vacation trips as a whole accounted for greater usage of the toll road than trips for other purposes—presumably because there were a few very short trips and many long trips with vacations as the purpose.

Vehicles traveling between Philadelphia and Pittsburgh used the turnpike to a very large extent regardless of purpose of trip and type of vehicle due to the large saving of time for all vehicles and of fuel as well for commercial vehicles.

ONE of the most difficult problems facing highway planning engineers is estimating the traffic which would use improved highways of various classes. This is important from the points of view of economic justification, priorities, and design features. With present emphasis on the completion of the National System of Interstate Highways the study of the usage of controlled-access highways, such as will constitute a large part of that system, assumes special importance.

When a high-type facility is constructed, there is a large diversion of traffic from roads immediately parallel and a lesser diversion from more distant roads. In addition, there is an increase in highway traffic throughout the area which is called traffic generation. A part of this increase is composed of trips diverted from public carriers, and an important part is composed of new trips which would not have been made if the improved facility had not been available. Furthermore, there is the long-range traffic growth or trend which follows generally the basic economic trend and takes place on highways of all classes throughout the country.

In estimating traffic usage of a proposed facility, therefore, the engineer must concern himself with these three factors: Diversion, generation, and long-range trend. To do this successfully, empirical data, properly analyzed, are needed. The Bureau of Public Roads, with the cooperation of the various State highway departments and other agencies, is endeavoring to supply these data and analyses to the extent practicable.

Other Traffic Studies Made

With regard to controlled-access facilities such as are contemplated in the Interstate system standards, several studies have been made and reported for highways in urban areas,[1] but very few for those in rural areas. There are few controlled-access free roads extending for long distances through rural areas and these have been opened to traffic only recently. There are, however, several toll roads or turnpikes built approximately to Interstate system standards, which have been in operation for a number of years and others which are being opened from time to time. These facilities offer good opportunities for study, though the deterring effect on traffic of the toll charges offers a complicating factor which must be evaluated in applying the results to free roads.

For a number of years the Bureau of Public Roads has cooperated with several States through the planning survey divisions of the highway departments in studies of toll-road traffic in relation to that on adjacent highways. The toll authorities have supplied at regular intervals information on traffic using the turnpikes. Such information, in addition to regular reports from the State highway departments concerning traffic volumes throughout the country, has given a broad picture of the changes in traffic flow which result from the construction of modern toll roads. This in itself, however, is not enough to permit accurate traffic estimates for any particular project under study.

Conclusions which can be drawn from this type of information are somewhat clouded by the fact that there is no differentiation between passenger car and truck traffic, or between trips which could conveniently be made on the turnpike and those which are purely local. Relations determined from traffic counts alone would be expected to vary widely in different areas according to the composition and characteristics of traffic in the area. In order to establish more basic relations, intensive traffic studies were made on several of the turnpikes. In these studies, drivers were interviewed at stations on roads parallel to the turnpike route both before and after the opening of the turnpikes, and at all turnpike interchanges under study after its opening. Questions were asked concerning trip origins and destinations, trip purpose, and other matters pertinent to the study.

Such studies were made in Maine, New Hampshire, New Jersey, Pennsylvania (eastern and western extensions), and Ohio. The "after" study has not been conducted in Ohio, because only one short section has been completed. In New Jersey the data are being analyzed. The results of the Maine Turnpike study have been partially reported to the Highway Research Board and a further report is included in this issue.[2] The present article reports the results of the study of the eastern extension of the Pennsylvania Turnpike which was opened to traffic in November 1950.

[1] *Traffic assignment*, Highway Research Board, Wash., D. C., Bulletin 61, publication 246, 1952; also *Gulf Freeway traffic survey, Houston, Texas.* Texas Highway Department, 1951.

[2] *Proportionate use of Maine Turnpike by traffic through Portsmouth-Portland corridor*, by J C Carpenter. Proceedings of the Highway Research Board, vol. 32, 1953, pp. 452-463; also *Traffic usage of Maine Turnpike*, by Glenn E. Brokke. Pages 224-230 of this issue.

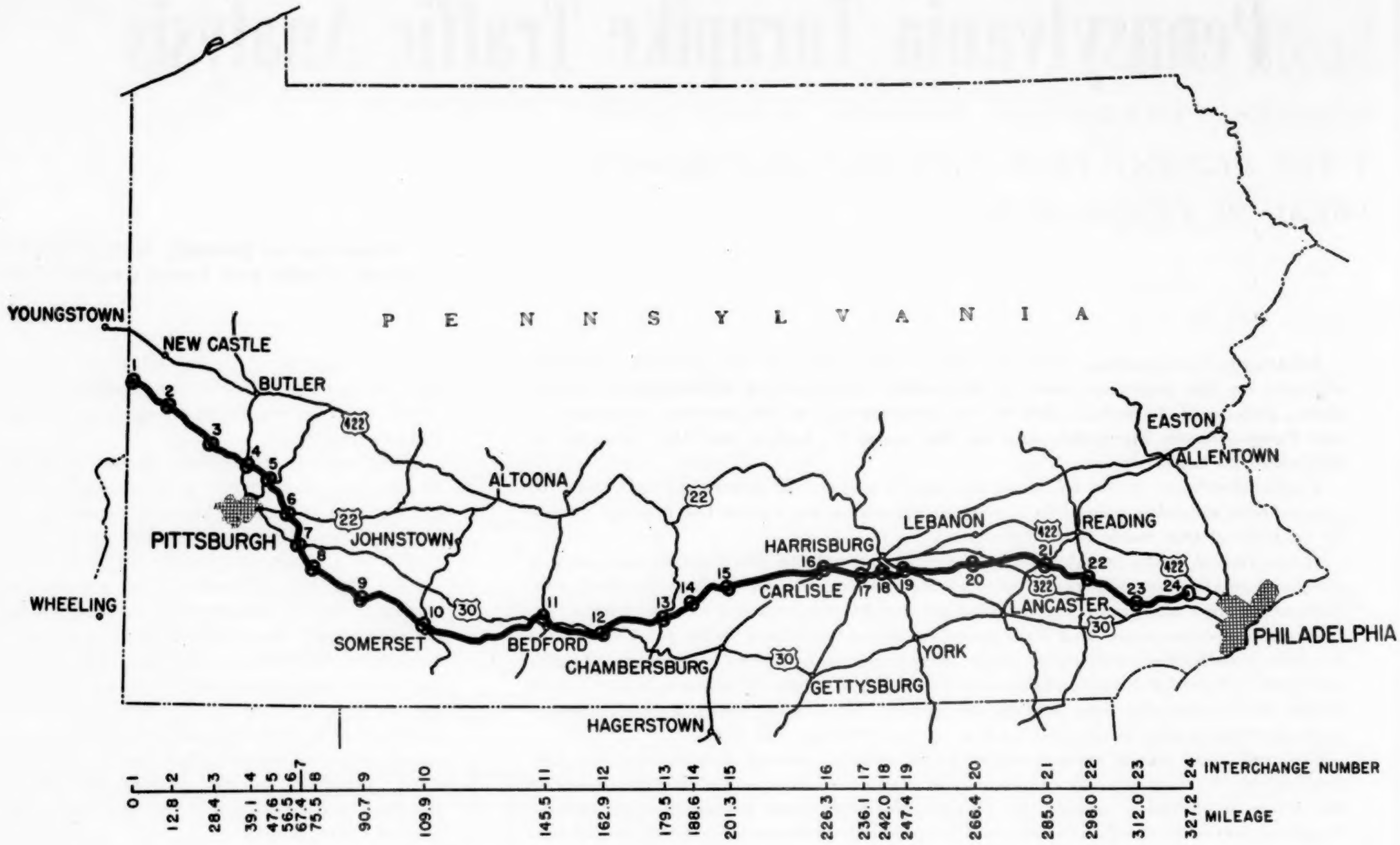


Figure 1.—Location of the Pennsylvania Turnpike.

Pennsylvania Turnpike Study

The location of the entire Pennsylvania Turnpike is shown in figure 1. The interchanges are indicated by the numbered circles, and mileages along the turnpike measured from the western terminus are shown at the bottom of the illustration.

The original section, which was opened in October 1940, extends from interchange 7 at Irwin (near Pittsburgh) to interchange 16 at Carlisle, a distance of 158.9 miles. A profile of this section of the turnpike and the principal parallel free routes (U. S. 30 and 11) appeared in a recent article in Public Roads.[3] The grades on the turnpike are much lighter and the total rise and fall much less than on the parallel free route. The rise and fall on the turnpike (original section) is 11,327 feet, compared to 26,257 feet on the free route. The comparatively low grades and saving in climb have much to do with the high usage of this section of the turnpike especially by trucks.

The eastern extension of the turnpike, which was opened in November 1950, extends from interchange 16 at Carlisle to interchange 24 at Valley Forge (near Philadelphia), a distance of 100.9 miles. It was on this section that the intensive traffic study was made. Origin and destination stations were operated in 1950 on one line just east of Harrisburg and on a second line about 20 miles west of Philadelphia before the turnpike was completed, and in 1952 after its construction. The location and types of survey stations are shown in figure 2, which is an enlargement of the study area.

There were 15 identical interview stations operated on the highways in the "before" and "after" studies made during June, July, and August of each of the 2 years. Additional interview stations were located at the turnpike interchanges and at 3 locations on the free highways in the after study. The stations were occupied on approximately the same dates in each year for the same number of hours. The duration of the operations was for at least a full 24-hour period on weekdays in June, July, or August. Additional 24-hour operations were made on Saturday and Sunday at a limited number of locations.

The topography along this section of the turnpike is generally level as compared with the rugged terrain through which the original section was built. There are four or more parallel routes in the eastern section from which traffic is diverted.

Since the major parallel routes are high-type and well-maintained highways, the big traffic obstacle in this area is the large number of towns and cities located on the regular routes. Such places cause traffic to slow down even when highways are adequate. During peak hours the highways in and near these municipalities are congested, and delays at such times may be considerable.

During the survey the routes connecting Valley Forge with Philadelphia were inadequate to serve properly the volume of traffic delivered by the turnpike. There was little choice between the routes from Valley Forge and from Paoli on U. S. 30 to Philadelphia. Both offered traffic resistance, especially during peak traffic periods. An expressway is under construction between Valley Forge and Philadelphia which will relieve this situation and may cause greater turnpike usage than occurred in 1952.

The turnpike has a minimum right-of-way width of 200 feet, and has four 12-foot traffic lanes divided by a 10-foot median strip in addition to acceleration and deceleration lanes at interchanges. There are 10-foot paved shoulders. The maximum grade is 3 percent, the maximum curve is 6 degrees, and the minimum sight distance is 1,000 feet.

The average distance between interchanges in the 327.2 miles between the Ohio State line and Valley Forge is 14.2 miles. The shortest section, 5.4 miles, crosses the Susquehanna River south of Harrisburg between interchanges 18 and 19, and adjoins the longest section on the eastern extension which is 19 miles in length and connects interchanges 19 and 20.

The speed limit for passenger vehicles on the turnpike is 60 miles per hour west of Breezewood, on the original section, and 70 miles per hour east of that point including the eastern extension. It is 45 and 50 miles per hour, respectively, for all other vehicles except where lower speeds are posted, such as in tunnels and at toll-gate approaches.

[3] *Operating characteristics of a passenger car on selected routes*, by Carl C. Saal. PUBLIC ROADS, vol. 28, No. 9, Aug. 1955, p. 181.

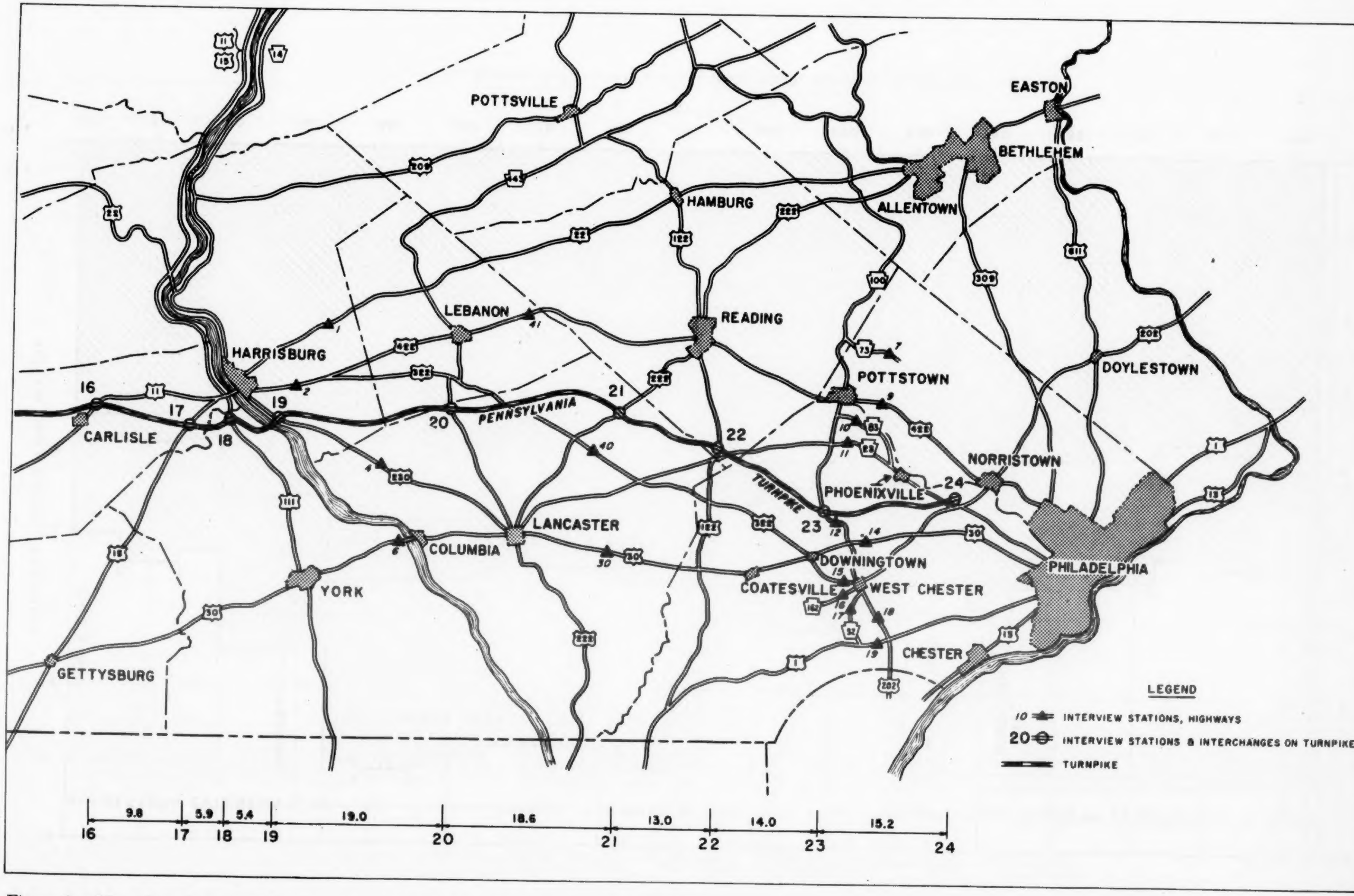


Figure 2.—Map of study area of the eastern extension of the Pennsylvania Turnpike showing the turnpike, other highways, and locations of roadside interview stations.

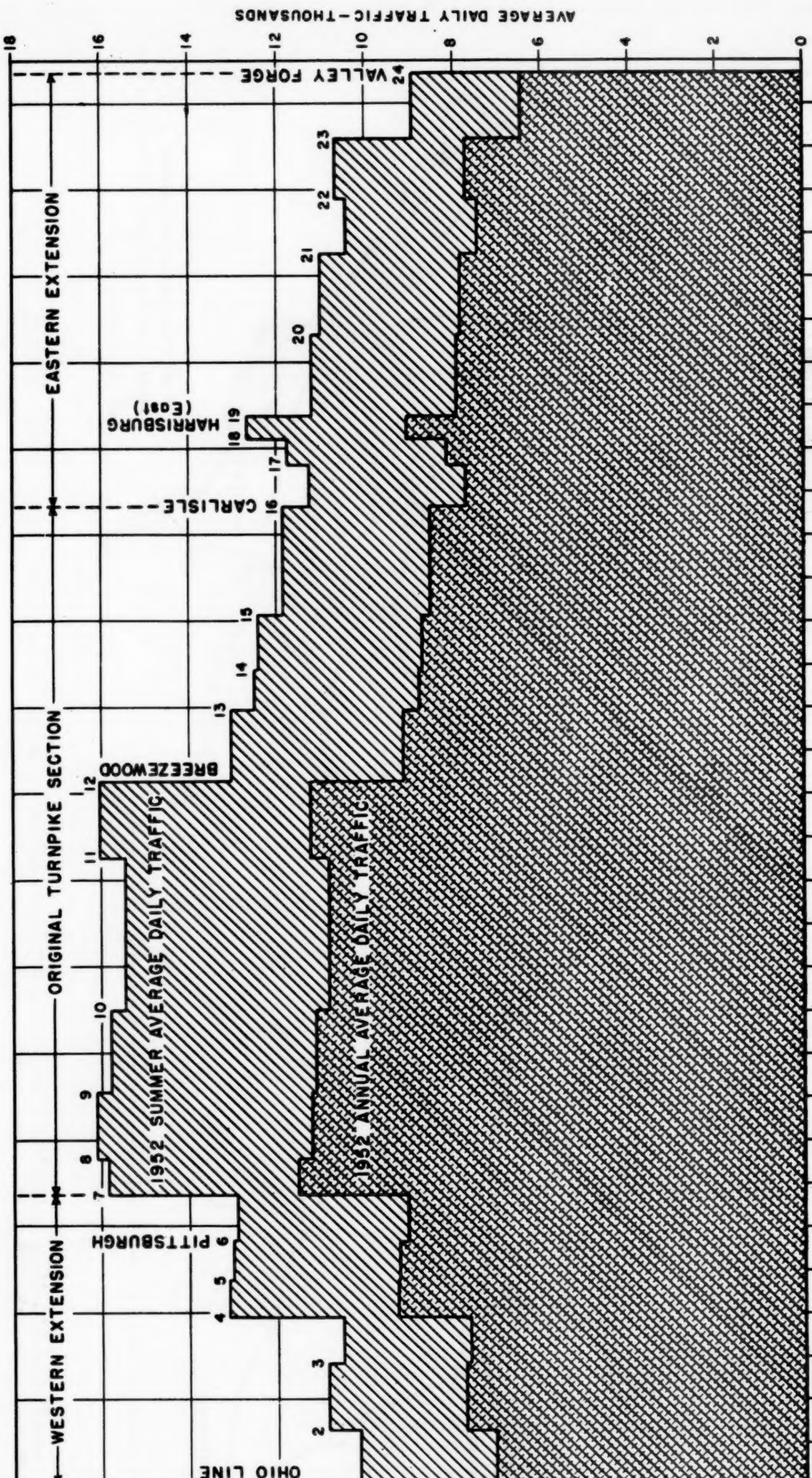


Figure 3.—Annual and summer average daily traffic between interchanges in 1952.

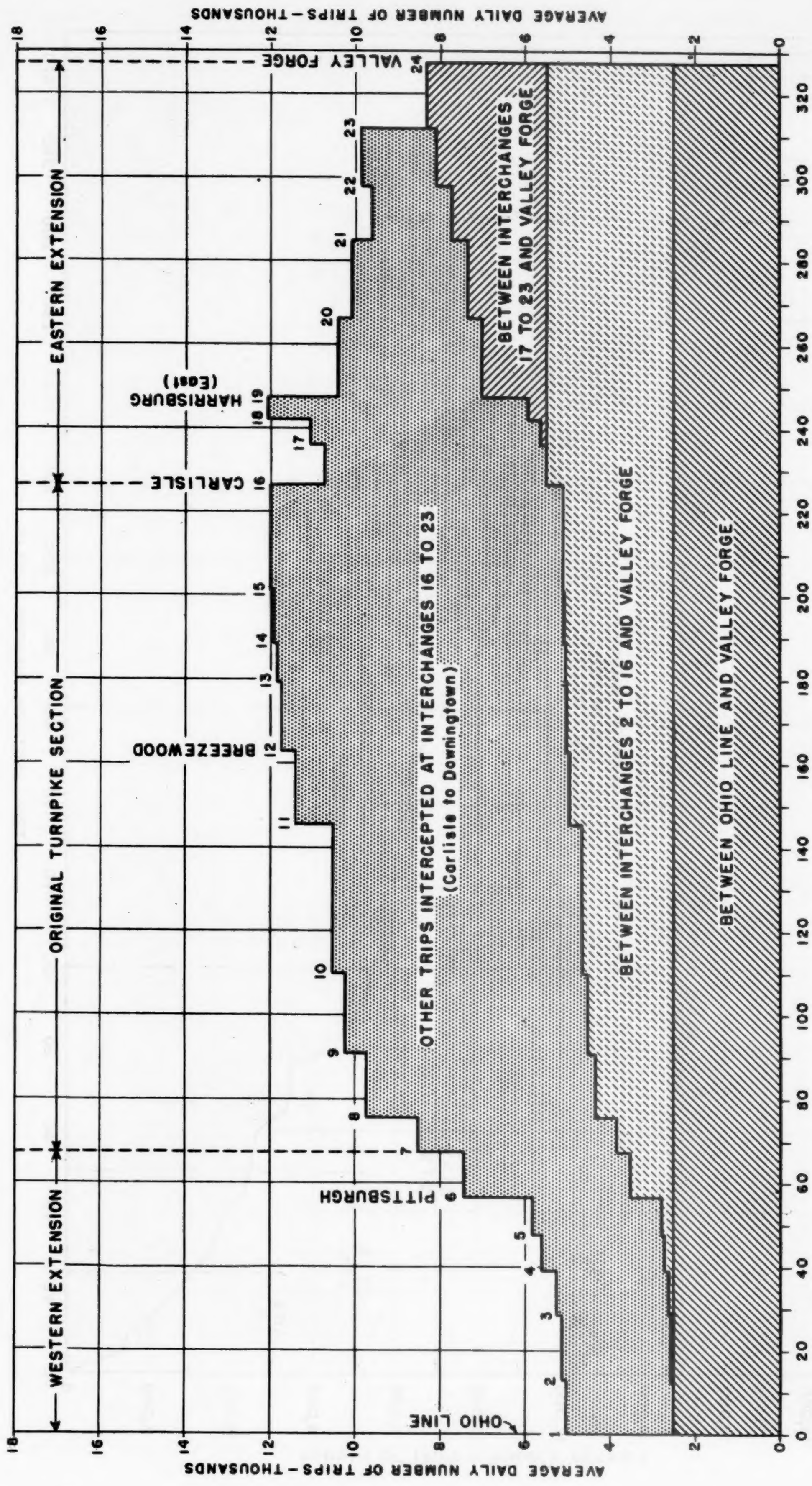


Figure 4.—Summer average weekday traffic between interchanges sampled in 1952 survey.

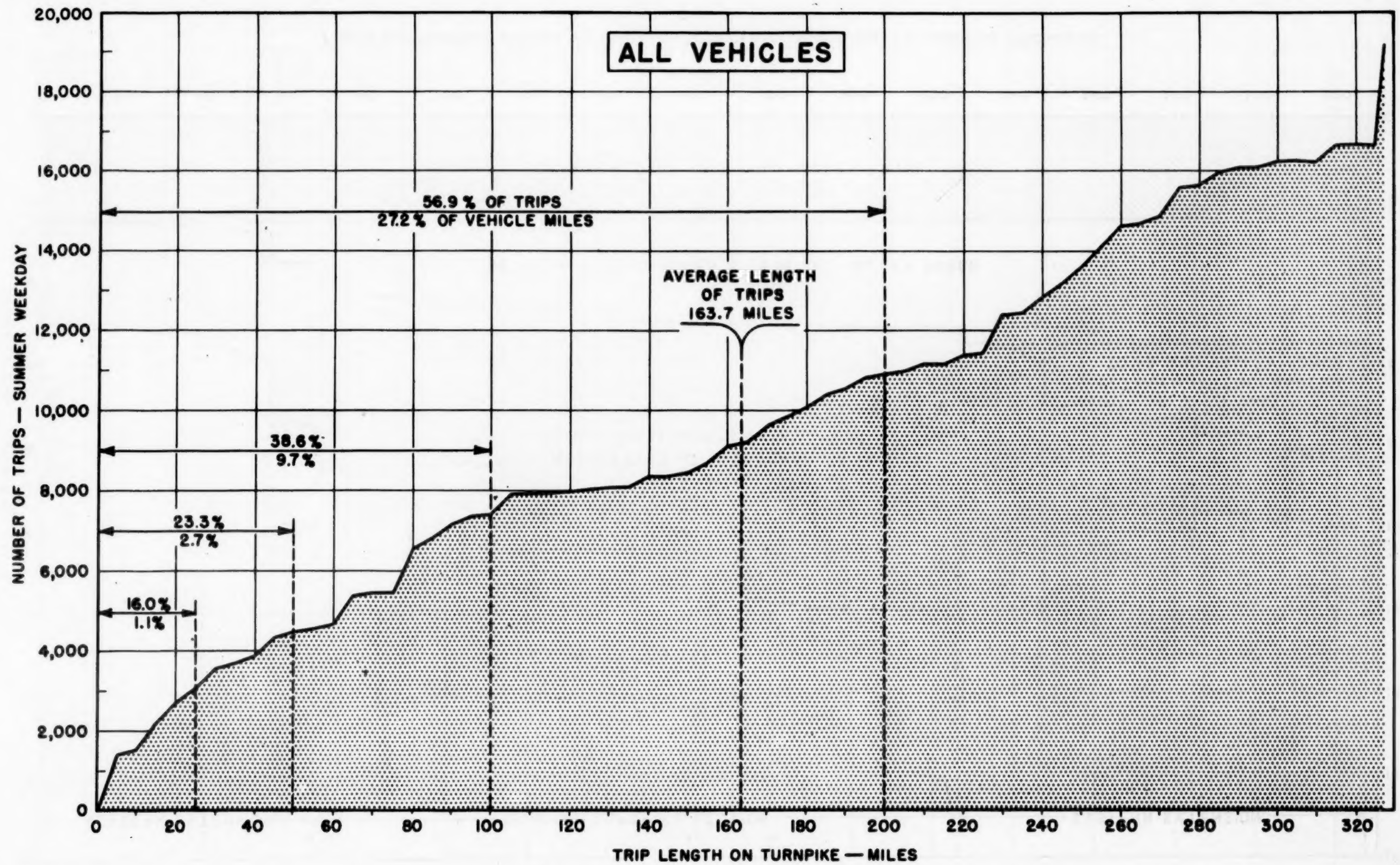


Figure 5.—Cumulative number of weekday trips related to miles of travel on the turnpike, and the number of such trips related to total trips and vehicle-miles.

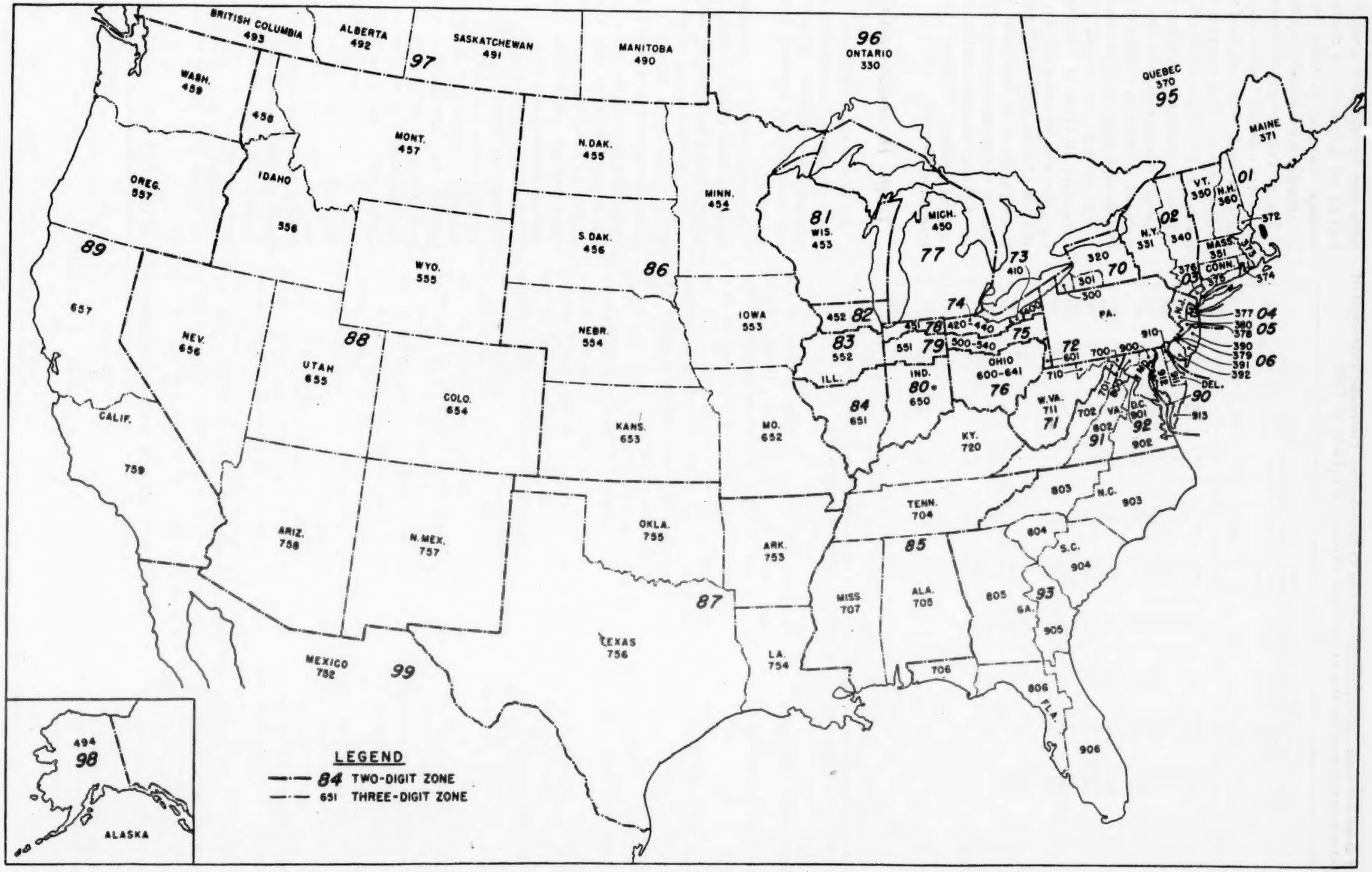


Figure 6.—Map of the United States indicating 2- and 3-digit zones, except for Pennsylvania.

Table 1.—Number of trips between interchanges on the Pennsylvania Turnpike intercepted on the eastern extension during an average summer weekday in 1952

Interchange	Carlisle (16)	Gettysburg Pike (17)	Harrisburg-West Shore (18)	Harrisburg East (19)	Lebanon-Lancaster (20)	Reading (21)	Morgantown (22)	Downingtown (23)	Valley Forge (24)	Total
1 Ohio State line	850	118	224	410	184	291	58	398	2,509	5,042
2 Beaver Valley	23	2	9	21	3	3	------	14	41	116
3 Perry Highway	18	1	8	10	7	5	1	18	56	124
4 Butler Valley	54	13	48	34	11	16	4	36	113	329
5 Allegheny Valley	33	5	10	27	15	13	2	35	60	200
6 Pittsburgh	193	45	101	198	57	98	30	174	746	1,642
7 Irwin	325	56	73	119	31	43	14	91	314	1,066
8 New Stanton	226	48	74	143	52	59	16	75	526	1,219
9 Donegal	122	26	39	57	15	14	7	35	171	486
10 Somerset	70	9	24	28	15	26	1	32	123	328
11 Bedford	198	22	62	101	22	57	13	78	314	867
12 Breezewood	109	9	7	34	10	29	3	34	73	308
13 Fort Littleton	33	6	12	12	3	6	1	7	27	107
14 Willow Hill	26	6	13	18	1	------	2	4	25	95
15 Blue Mountain	27	5	2	12	1	------	------	19	17	83
16 Carlisle	------	31	87	281	61	86	15	65	373	999
17 Gettysburg Pike	------	------	96	400	54	44	7	17	145	763
18 Harrisburg-West Shore	------	------	------	1,401	78	52	14	61	307	1,913
19 Harrisburg East	------	------	------	------	140	147	51	233	1,072	1,643
20 Lebanon-Lancaster	------	------	------	------	------	36	41	63	355	495
21 Reading	------	------	------	------	------	------	67	86	363	516
22 Morgantown	------	------	------	------	------	------	------	194	394	588
23 Downingtown	------	------	------	------	------	------	------	------	233	233
Total	[1] 2,307	402	889	3,306	760	1,025	347	1,769	8,357	19,162

[1] Trips off or on at Carlisle and traveling to or from the west did not use the eastern extension.

Traffic Between Interchanges

The average daily traffic volume on all sections of the turnpike, in the summer and throughout the year, is shown in figure 3. Saturdays and Sundays as well as weekdays are included. The volume on the original section is greater than that on either the eastern or western extension. The summer traffic is about 29 percent greater than the average annual traffic.

The trips intercepted on the eastern extension of the turnpike were analyzed on the basis of point of entry and point of exit to determine their travel on the turnpike. The results are shown in figure 4 for an average summer weekday.

The hatching at the bottom of the chart indicates the trips over the whole length of the Pennsylvania Turnpike between the Ohio State line and Valley Forge. The next group includes vehicles on trips that used the full length of the eastern extension extending from Valley Forge to Carlisle or farther west. The third group of trips are those intercepted at Valley Forge which are shorter than the length of the eastern extension. This accounts for the total trips at Valley Forge. The remaining trips are those which do not extend to Valley Forge, but enter or leave the turnpike between Carlisle and Downingtown. The latter group includes trips entirely on the eastern extension as well as those on all or portions of the turnpike west of Carlisle.

The apparent decrease in turnpike use west of the eastern extension is due to the omission in figure 4 of all trips which enter and leave the turnpike between the Ohio State line and a point west of Carlisle. Such trips were not sampled in the eastern extension study.

The length of that portion of a trip which lies between the termini of a controlled-access facility is important in determining diversion to the facility. It is of particular interest to note some of the results found in this study regarding the length of that portion of the trips found on the turnpike itself. There were 2,509 vehicles, making up approximately 25 percent of the vehicle-mileage on the eastern extension of the Pennsylvania Turnpike, that used the entire 327 miles in traveling between the Ohio line and Valley Forge. Another 2,979 vehicles traveled at least the 101 miles of the eastern extension between Valley Forge and Carlisle. This number of trips adds to 55 percent of the vehicle-mileage on the eastern extension during the summer months. That is, during the period of the survey, more than one-half of the vehicle-miles of travel on the eastern extension resulted from through trips on it (see fig. 4 and table 1). Almost two-thirds of the vehicles intercepted at Valley Forge traversed the whole length of the eastern extension.

There were 19,162 trips intercepted in the 1952 study on the eastern extension. Of this total, 2,307 vehicles were off or on at Carlisle traveling to or from the west and did not use the eastern extension.

Table 2 shows the percentages of the turnpike trips and of the vehicle-mileage by these trips, on different lengths of the turnpike. For example, 8.0 percent of the turnpike trips were less than 10 miles in length, and accounted for only 0.3 percent of the turnpike vehicle-mileage. All but 38.6 percent of the trips were for distances greater than 100 miles and all but 9.7 percent of the turnpike vehicle-mileage was due to these long trips. This information is presented graphically in figure 5.

The average length of the turnpike portion of the trip was 163.7 miles which is, of course, less than the average length of trip from origin to destination. This figure is somewhat misleading, however, since stations were operated only on the eastern extension and short trips between interchanges on the other sections were not included in the sample, whereas all of the through trips were included.

The average trip length determined from tickets for all types of vehicles for the whole turnpike was 98 miles for the year 1952 and 105 miles for the period of the survey. If only the mileage on a particular section is considered, the annual average length of trips was as follows: Eastern extension, 55 miles; original section, 97 miles; and the western extension, 39 miles.

Traffic Diversion and Generation

As previously mentioned, the traffic that uses a new facility is composed of both diverted and generated traffic. It is difficult to separate the amount diverted from the amount generated.

Diverted traffic is composed of vehicles traveling over existing roads before the construction of a new facility, and then transferring to the new route after its completion. When there is a saving in time, drivers generally transfer to a high-type free facility. Fewer of such trips are diverted to a toll road. It is desirable to determine what proportion of eligible or potential trips between particular zones actually use the toll road and whether time or distance is saved.

The term "generated traffic" as used by highway engineers in various areas of the country often has different meanings. The American Association of State Highway Officials has defined the term in one of its publications.[4] As used in this article, however, generated traffic refers to the amount of traffic using a new road, plus that on the old roads in the corridor, less the amount that would have been expected on the old highways had not the new facility been constructed. That is, additional trips made over and above those diverted from nearby roads to the new facility—generally those which were not made

[4] *A policy on geometric design of rural highways.* American Association of State Highway Officials, Wash., D. C., 1954, p. 66.

Table 2.—Number of trips and vehicle-miles of travel by turnpike trip-length groups

Trip length, in miles	Trips for all vehicles: Total for group: Number	Trips for all vehicles: Total for group: Percent of total	Trips for all vehicles: Cumulative total: Number	Trips for all vehicles: Cumulative total: Percent of total	Vehicle-miles of travel: Total for group: Number	Vehicle-miles of travel: Total for group: Percent of total	Vehicle-miles of travel: Cumulative total: Number	Vehicle-miles of travel: Cumulative total: Percent of total
Under 10	1,528	8.0	1,528	8.0	8,436	0.3	8,436	0.3
10–25	1,543	8.1	3,071	16.1	24,851	.8	33,287	1.1
25–50	1,389	7.2	4,460	23.3	50,929	1.6	84,216	2.7
50–100	2,935	15.3	7,395	38.6	221,631	7.0	305,847	9.7
100–200	3,505	18.3	10,900	56.9	548,440	17.5	854,287	27.2
200–300	5,314	27.7	16,214	84.6	1,325,247	42.3	2,179,534	69.5
300–327	2,948	15.4	19,162	100.0	958,011	30.5	3,137,545	100.0

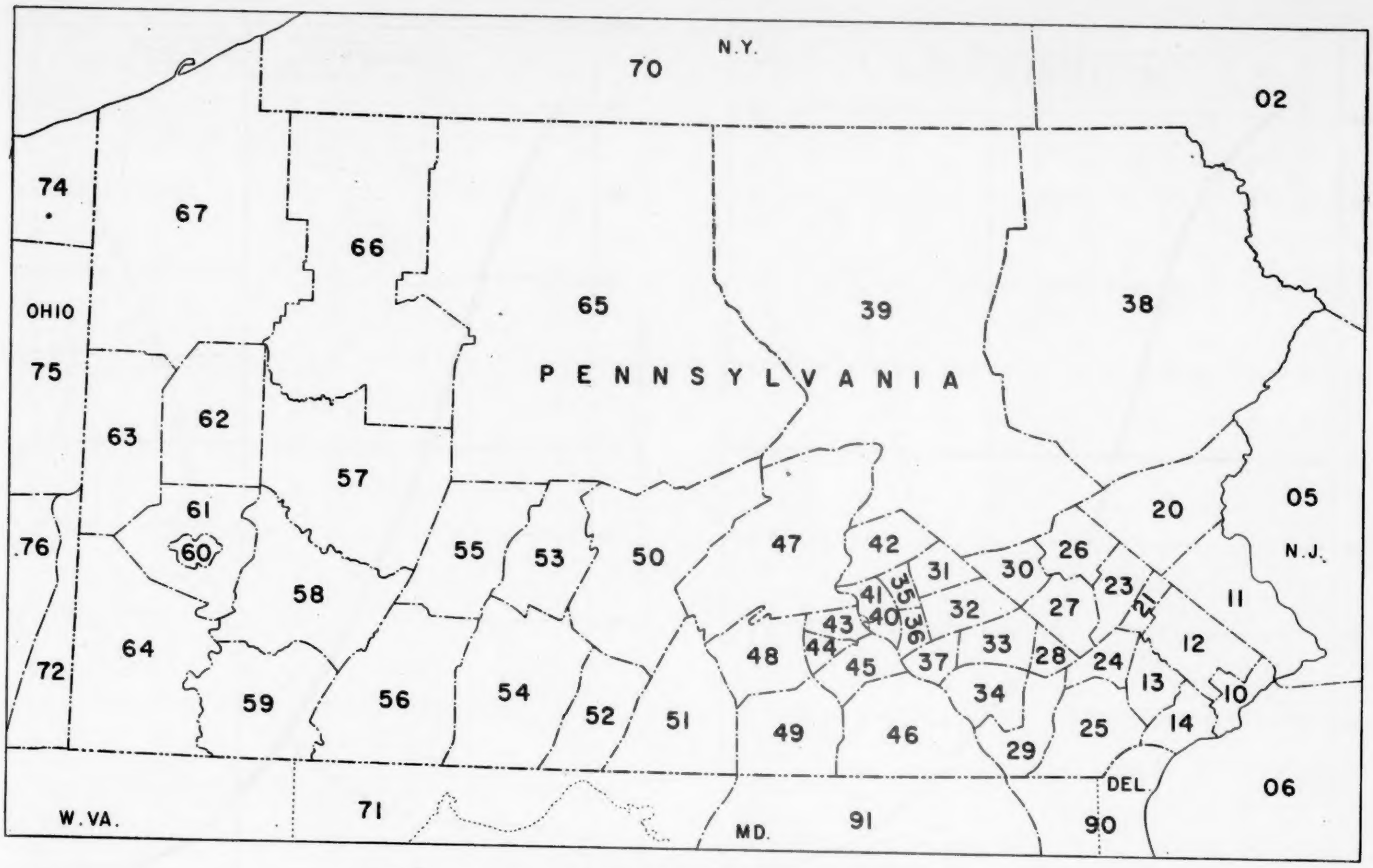


Figure 7.—Map of Pennsylvania indicating 2-digit zones.

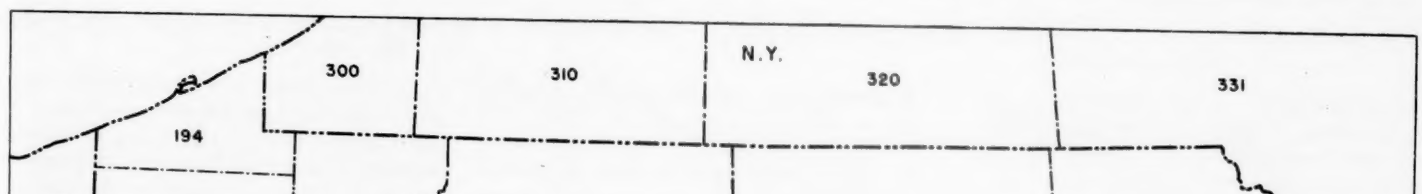


Figure 8.—Map of Pennsylvania indicating 3-digit zones.

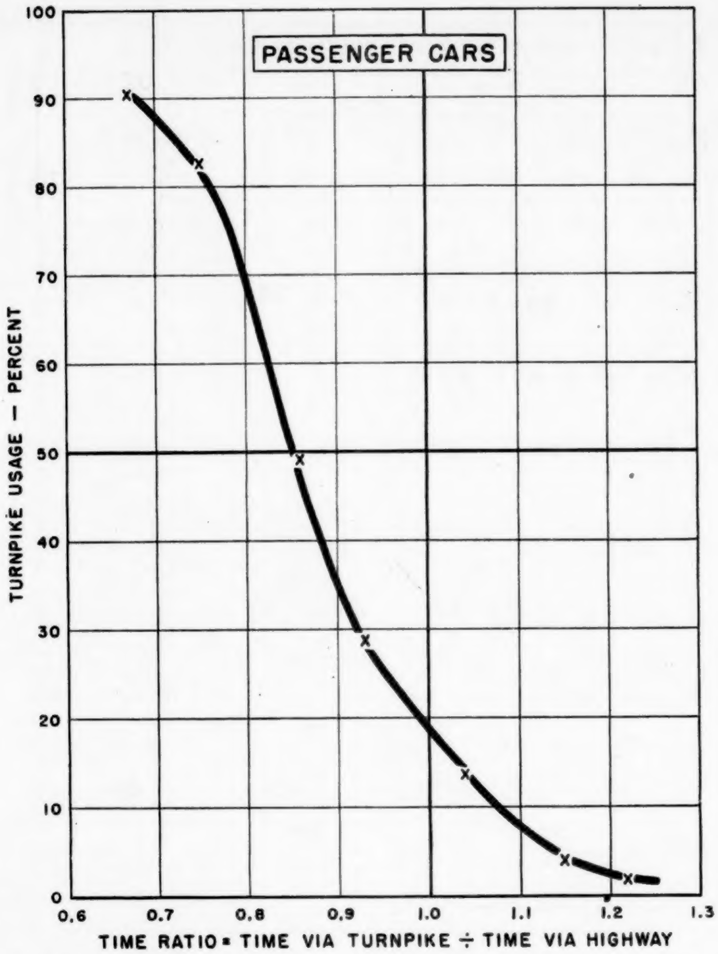


Figure 9.—Turnpike usage by passenger cars in relation to the time ratio.

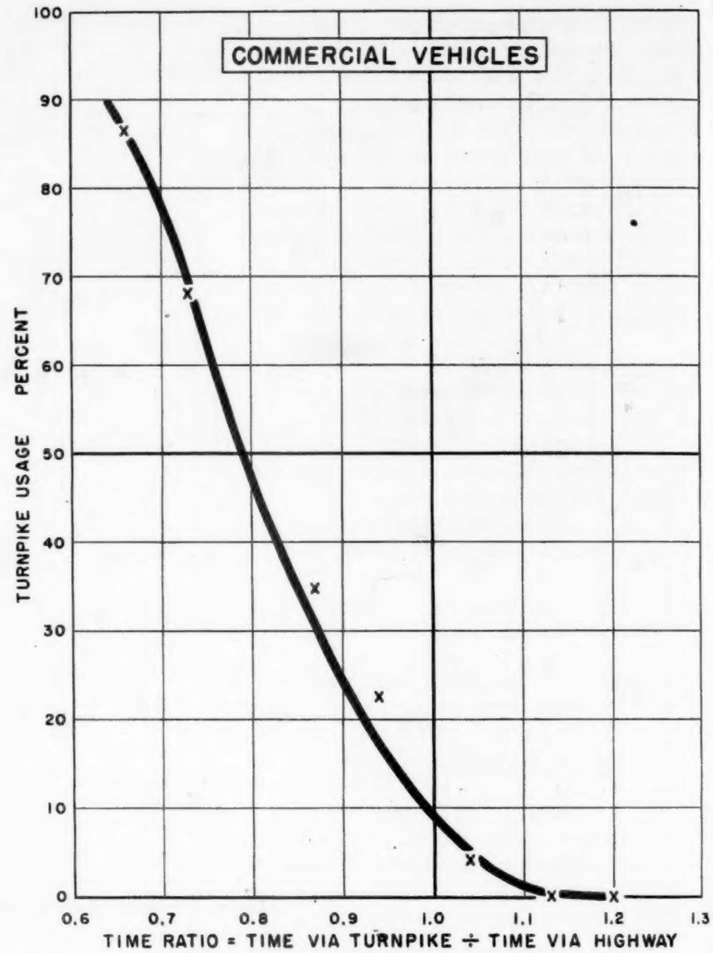


Figure 10.—Turnpike usage by commercial vehicles in relation to the time ratio.

at all, or were made by other means before the new facility was built. It is also possible that some trips were included which were diverted from roads so far away that they did not pass any of the survey stations. Some of the generated traffic occurs on free highways due to the transfer of former traffic to the toll facility, thereby making the old roads more attractive. The additional traffic, above diversion, that occurs on the new road, however, is of principal interest.

In addition to the diverted and generated traffic, it often happens over a period of years that additional traffic results from the development of new communities, industries, and businesses along the new highway. This development traffic, unless it occurs almost immediately after the opening of the facility, is not recognizable as generated traffic, but appears rather as a faster than normal growth.

Origin and Destination Zones

The comparison of travel time and distance on the old highways between major points or zones with the travel time and distance between the same points or zones by way of the new highway, and other relations based on these factors, provide tools for estimating the usage of a proposed facility. Trips between zones need to be analyzed to determine the percentages of trips that actually use the new and superior route.

As the basis for such an analysis, Pennsylvania as well as the rest of the country was divided into geographic zones. Comparatively small zones designated by three-digit numbers were first selected, but a preliminary review of the data indicated they were too small for proper analysis. After studying the detailed trip movements between individual zones, certain of the smaller zones were combined into two-digit zones to facilitate the analysis of the data.

Figure 6 shows both two- and three-digit zones for the United States except Pennsylvania. Two- and three-digit zones for Pennsylvania are shown in figures 7 and 8, respectively.

Time and Distance Data

Time and distance runs, "floating with traffic," were made on the turnpike and the highway routes between zones. The time and distance over logical free highways from origin to destination and via the turnpike, using the most logical free routes to and from the turnpike, were compared.

Based on nationwide speed studies and data from the Pennsylvania Turnpike Commission, the difference in speed between passenger cars and commercial vehicles was established as being generally 5 miles per hour. That is, if passenger cars traveled at 40 miles per hour, trucks were assumed to travel at 35 miles per hour. Where the speed was very low, 20 miles per hour or under, truck speeds were assumed to be the same as for passenger cars. The passenger-car speed on the turnpike was established at 57 miles per hour, and for commercial vehicles, 52 miles per hour on the eastern extension and 49 miles per hour on the remainder of the turnpike.

The average speed on the turnpike is approximately that of the driving speed. However, on regular highways the average speed is much below the driving speed on the open highway. It is for this reason that speeds used for free highways in this study are below speeds reported in general by State agencies and by the Bureau of Public Roads for rural highways. The speeds ordinarily reported are for level tangents on the open road, and do not reflect the time lost passing through towns and cities, or driving on tortuous curves and in hilly terrain. Time in this study includes that for passing through the many towns found in Pennsylvania, or from center to center of the municipalities.

An additional factor was involved for trips via the turnpike. Extra time and distance were required to get on the turnpike, pick up the ticket, pay the toll on leaving, and return to the regular highway. These actions added about 1 mile in distance and 4 minutes in time, on the average. Consequently, these amounts were added to turnpike data before computing the time and distance ratios, and time or distance saving or loss.

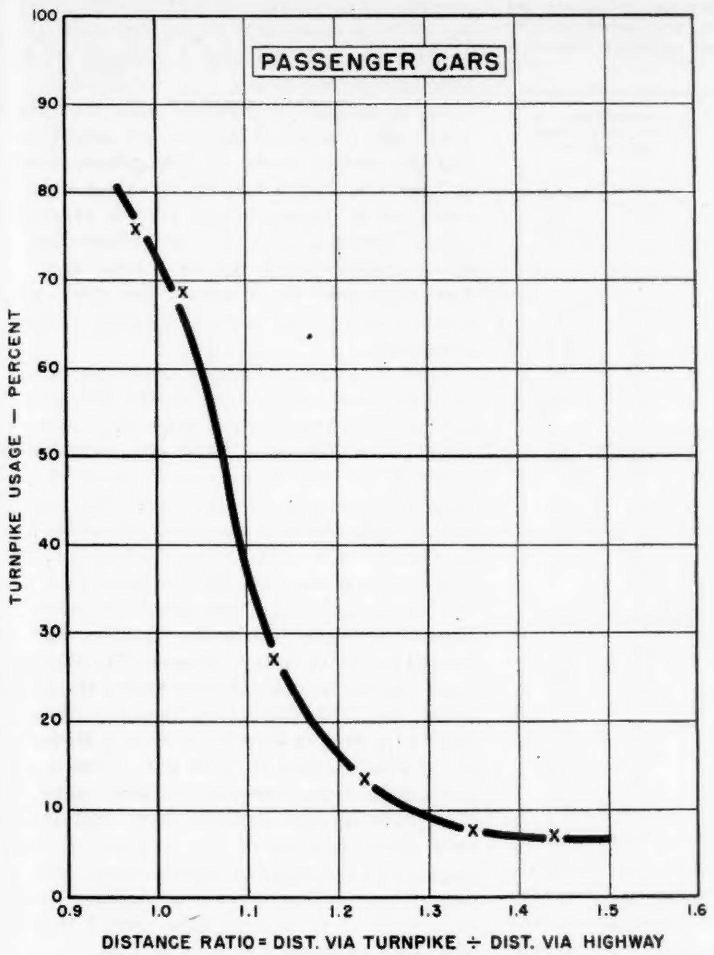


Figure 11.—Turnpike usage by passenger cars in relation to the distance ratio.

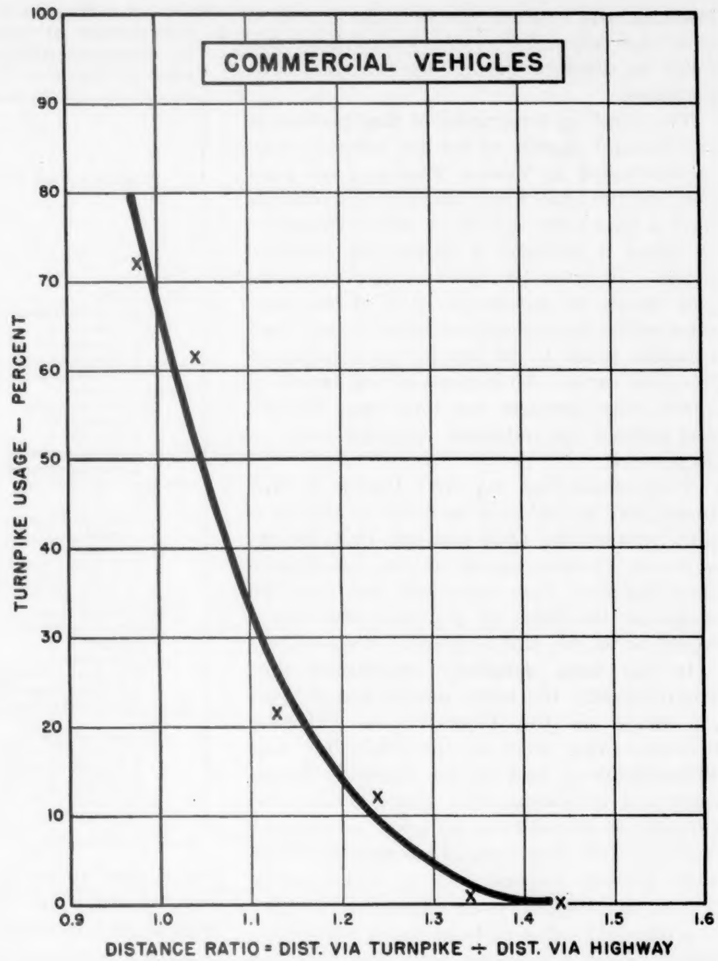


Figure 12.—Turnpike usage by commercial vehicles in relation to the distance ratio.

The data developed were on a zone-to-zone basis, as previously indicated, and the travel time and distance between the centers (usually, but not necessarily the geographic centers) of zones via logical routes and via the turnpike were computed. Where zones are large, it is possible that trips from that portion of the zone nearest the facility will use it to a larger extent than those farthest away. The use of actual origins and destinations for individual trips would result in more accurate ratios, but analysis in such detail would be time consuming, costly, and impracticable in this study. In any event, the application would ordinarily be by zones and the method used was, therefore, in keeping with the normal application of the results.

Experience in analysis of the Pennsylvania data indicates that the use of a toll road by drivers is not always determined on the basis of saving of time or distance. For example, it was found that some of the motorists paid toll to use the turnpike, even though they lost both time and distance in so doing. Some of them probably did not know whether they could save time by using the turnpike, while others perhaps did so intentionally preferring to use a high-type facility. Notwithstanding a certain amount of erratic behavior of this kind, time and distance relations do seem to be fairly reliable measures of the percentage use of the turnpike by trips between different pairs of zones.

Turnpike Usage Related to Time and Distance

The percentage of trips on the turnpike was determined in relation to time ratio (travel time via the turnpike divided by travel time via free routes), distance ratio (travel distance via turnpike divided by travel distance via free routes), products of these ratios, and amount of time saved and lost for passenger cars and commercial vehicles separately. So far as is known, this is the first time such relations have been established for a toll road.

First, the percentage of turnpike use was plotted separately for each zone-to-zone movement. This resulted in considerable scatter, largely because of the small number of trips between some of the zones. To determine the final curves for the various factors in relation to turnpike usage, it was therefore considered desirable to combine the ratios or minutes saved or lost into groups. These were averaged both for turnpike usage and for other factors to obtain central points through which the final curves were drawn.

In most instances, it was found that a simple average of the percentage turnpike use between pairs of zones falling into the same group of ratios or minutes was preferable to an average weighted in accordance with the number of trips between each pair of zones. This was likely due to the very large number of trips from certain urban zones where the usage ratio was not comparable to those for other zones. By weighting in such cases, the unusual movement had entirely too much influence on the curve.

Turnpike Usage Related to Time Ratio

Time ratios for trips between the various zones were computed for passenger cars and commercial vehicles separately. The percentage of turnpike use was plotted against the time ratios, grouped as previously explained. The resulting curves are shown in figures 9 and 10.

The time ratio was computed by dividing the travel time for the toll facility by the travel time for regular highways. The time required to travel the separate routes was obtained from runs made by the floating-car method as previously indicated.

In case the trip extended beyond the ends of the turnpike, time and distance were not figured for the entire trip in computing ratios, but for only that portion within the turnpike area. In this procedure, "points of choice" were designated; that is, for computation purposes, the termini of the longer trips were considered as the points where drivers made a choice of whether the turnpike would be used. The reason for using this procedure is that travel time and distance for the portion of a trip lying beyond the turnpike area are the

same for trips made on the turnpike and those which are not, and the ratios tend to approach unity as distance beyond the turnpike area increases.

The effect on time ratios of that portion of the trip not eligible to use the turnpike may be illustrated as follows: Passenger-car trips between the Ohio State line and Philadelphia have a time ratio of 0.65 for which the curve in figure 9 indicates a 92-percent turnpike usage. An extra 100 miles beyond the turnpike causes an increase to 0.73 of the time ratio with a consequent reduction of indicated turnpike usage to 85 percent as determined from the curve. An increase in trip length of 1,000 miles increases the time ratio to 0.91 and reduces the indicated turnpike usage to 33 percent.

This means that the three groups of trips considered, which could be made on the turnpike between the Ohio line and Philadelphia and save the same amount of time, would have three different time ratios, and the turnpike usage on the basis of the time-ratio curve would be 92, 85, and 33 percent, respectively.

It has been definitely established that approximately the same percentage of trips are made on the Pennsylvania Turnpike between zones west of the Ohio line and Philadelphia or east of the Delaware River, regardless of whether the origin is near the turnpike or at points as far away as the west coast or New England. Therefore, for trips with termini beyond the turnpike where drivers could logically use either the turnpike or a parallel road, a point of choice was established before computing time and distance ratios. Trips with origin or destination west of Pennsylvania were assigned the Ohio line as an approximate point of choice. Deerfield, Ohio, was used for points to the north, such as Cleveland, Ohio, and Michigan; Canton, Ohio, for trips normally using U. S. 30; and Washington, Pa., for trips between the southwest and east that pass through the Pennsylvania corridor. It was found that a point of choice appeared to be near Somerville, N. J., for trips with origin or destination in northern New Jersey and beyond Somerville.

Because the points of choice are definite points on the highway, the time and distance ratios for trips extending beyond the turnpike area are more accurate than the ratios for trips with both termini within the turnpike area, where time and distance are measured from center to center of zone. In the latter case, the time and distance for many of the trips differ materially from the measurements because origins and destinations may be near the edge rather than the center of the zone. This is one of the factors causing the previously mentioned scatter in the plotted points for zone-to-zone movements.

Table 3.—Standard error of estimate of percentage of turnpike use based on the variation of points from a final curve in each category

Turnpike usage criteria	Standard error of percentage of turnpike use for— Passenger cars	Commercial vehicles
	Percent	*Percent*
Time ratio:		
Individual points	12.3	17.1
Averages of—		
0.01 ratios	6.2	11.9
0.05 ratio groupings	2.2	4.3
0.10 ratio groupings	.9	2.8
Distance ratio:		
Individual points	21.2	24.2
Averages of—		
0.01 ratios	11.8	11.6
0.05 ratio groupings	4.4	5.3
0.10 ratio groupings	1.2	4.3
Product of time and distance ratios:		
Individual points	13.9	17.8
Averages of—		
0.01 ratios	10.3	13.2
0.05 ratio groupings	4.3	3.8
0.10 ratio groupings	2.7	1.3
Product of time ratio squared and distance ratio:		
Individual points	12.6	18.2
Averages of—		
0.01 ratios	13.3	16.6
0.05 ratio groupings	4.1	6.5
0.10 ratio groupings	2.7	2.9
Time differential (time saved or lost):		
Individual points	11.9	13.5
Averages of groupings by—		
5-minute intervals	8.5	12.9
10-minute intervals	7.8	11.7
15-minute intervals	3.4	11.1
30-minute intervals	----------	5.6

There are other important factors, however, contributing to this scatter. Drivers do not all travel at the same speed, so the time ratios between the same points vary among drivers. Also, the ease of driving on the turnpike appeals to some more than others and where a toll is involved, the financial status of individuals has an important bearing on the choice of route.

Because of these factors, it is impossible to determine whether a particular trip will be made on the turnpike, particularly if the time ratio is between 0.85 and 1.05, but it is possible to determine with a reasonable degree of accuracy the percentage of drivers that will do so. Within reasonable limits, therefore, it is possible to assign trips to a turnpike on the basis of the time ratio.

In the method of grouping used, the variations just mentioned have been ironed out and the plotted points for the groups shown as X's in the figures fall very close to a smooth curve, as in figures 9 and 10, for example. Before deciding upon the groupings shown, other smaller groupings were tried and, in some instances, the shape of the curve was influenced to some extent by these smaller groupings.

From the curve in figure 9, the proportion of turnpike usage can be read for the time ratios computed for travel of passenger cars between zones. For example, when the time ratio was 0.67 or less, 90 percent or more of the trips were made on the turnpike. For a time ratio of 0.80, the percentage use approximated 69 percent; for 0.90, it was 35 percent; for 1.00 or equal time via the turnpike and via the free road, it approximated 19 percent. Because of higher speeds the distance via the turnpike was, of course, greater than the distance via the free routes when travel time was equal; and it would appear that almost one-fifth of the drivers traveled this extra distance, saved no time, and yet paid toll. This is not necessarily true, however, because some of these drivers may actually have had lower time ratios because of the location of their origins and destinations within zones, driving habits, or other factors. The turnpike usage dropped to 7 percent at time ratio 1.10 and was down to about 2 percent at 1.20.

The curve for commercial vehicles shown in figure 10 was drawn on the basis of groupings similar to those used in plotting figure 9 for passenger cars. The curve for commercial vehicles is somewhat steeper, and there is, on the whole, a lesser percentage of turnpike use for commercial vehicles than for passenger cars. For the whole curve, assuming even distribution throughout, approximately three-fourths as great a percentage of commercial vehicles as passenger cars used the turnpike. This percentage, of course, varies according to where the trip-time ratio falls on the curve.

Figure 14 (Right).—Turnpike usage by commercial vehicles in relation to the product of time and distance ratios.

Table 4.—Through trips of passenger car, commercial, and total vehicles between selected cities, together with the number and percentage of trips using the turnpike on an average summer weekday, 1950–52

Year and location	Passenger cars: Using turnpike: Number	Passenger cars: Using turnpike: Percent of total	Passenger cars: Total	Combinations: Using turnpike: Number	Combinations: Using turnpike: Percent of total	Combinations: Total	Other commercial: Using turnpike: Number	Other commercial: Using turnpike: Percent of total	Other commercial: Total	All commercial: Using turnpike: Number	All commercial: Using turnpike: Percent of total	All commercial: Total	All vehicles: Using turnpike: Number	All vehicles: Using turnpike: Percent of total	All vehicles: Total
1950:															
Pittsburgh–Philadelphia	171.1	87.3	196.1	170.7	90.7	188.1	33.7	87.3	38.6	204.4	90.2	226.7	375.5	88.8	422.8
1951:															
Pittsburgh–Philadelphia	209.4	91.0	230.1	171.8	95.6	179.7	36.7	80.5	45.6	208.5	92.5	225.3	417.9	91.8	455.4
Pittsburgh–Harrisburg	184.9	89.7	206.1	37.3	94.2	39.6	6.5	100.0	6.5	43.8	95.0	46.1	228.7	90.7	252.2
1952:															
Pittsburgh–Philadelphia	227.1	88.5	256.5	162.6	86.0	189.1	26.9	82.8	32.5	189.5	85.5	221.6	416.6	87.1	478.1
Harrisburg–Philadelphia	497.6	75.6	658.2	25.4	22.6	112.3	37.9	59.4	63.8	63.3	35.9	176.1	560.9	67.2	834.3

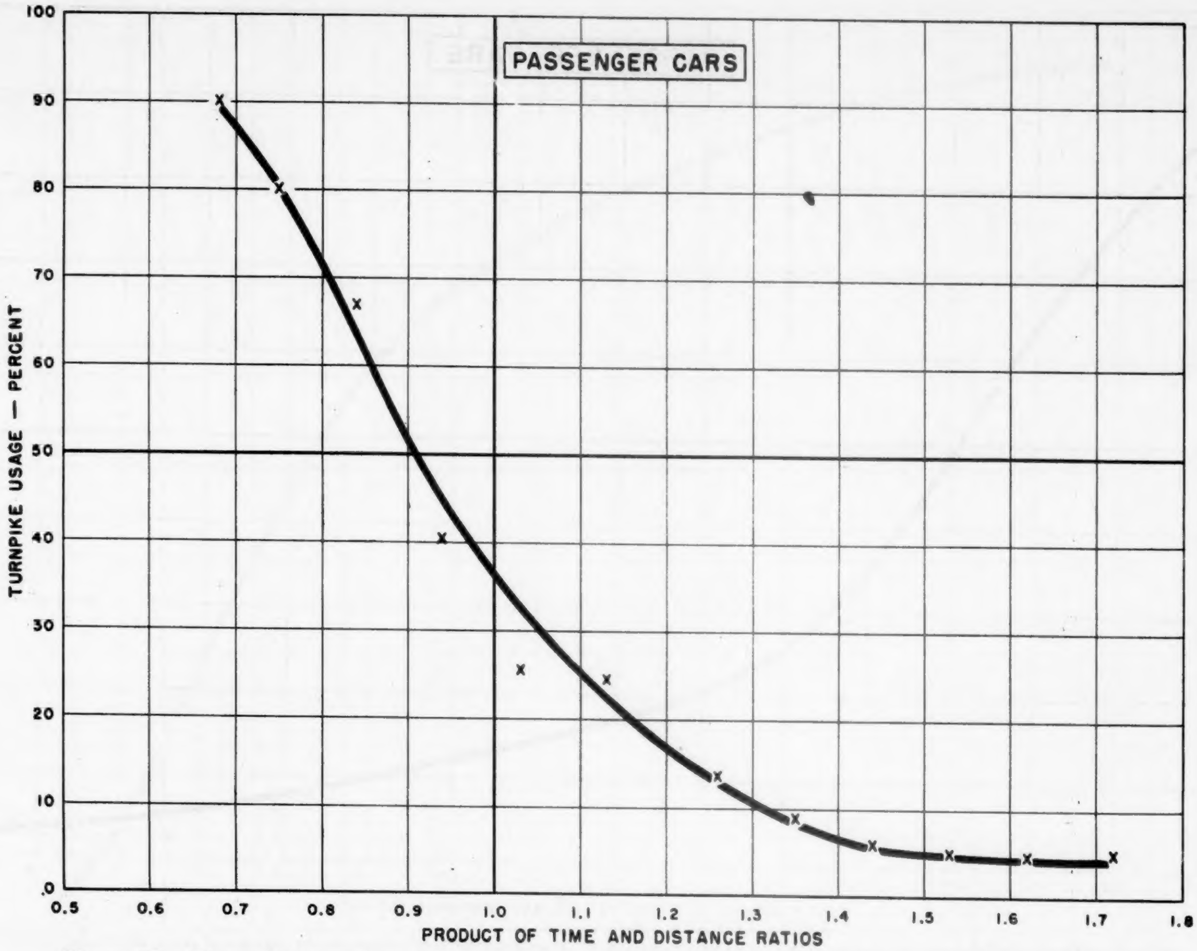
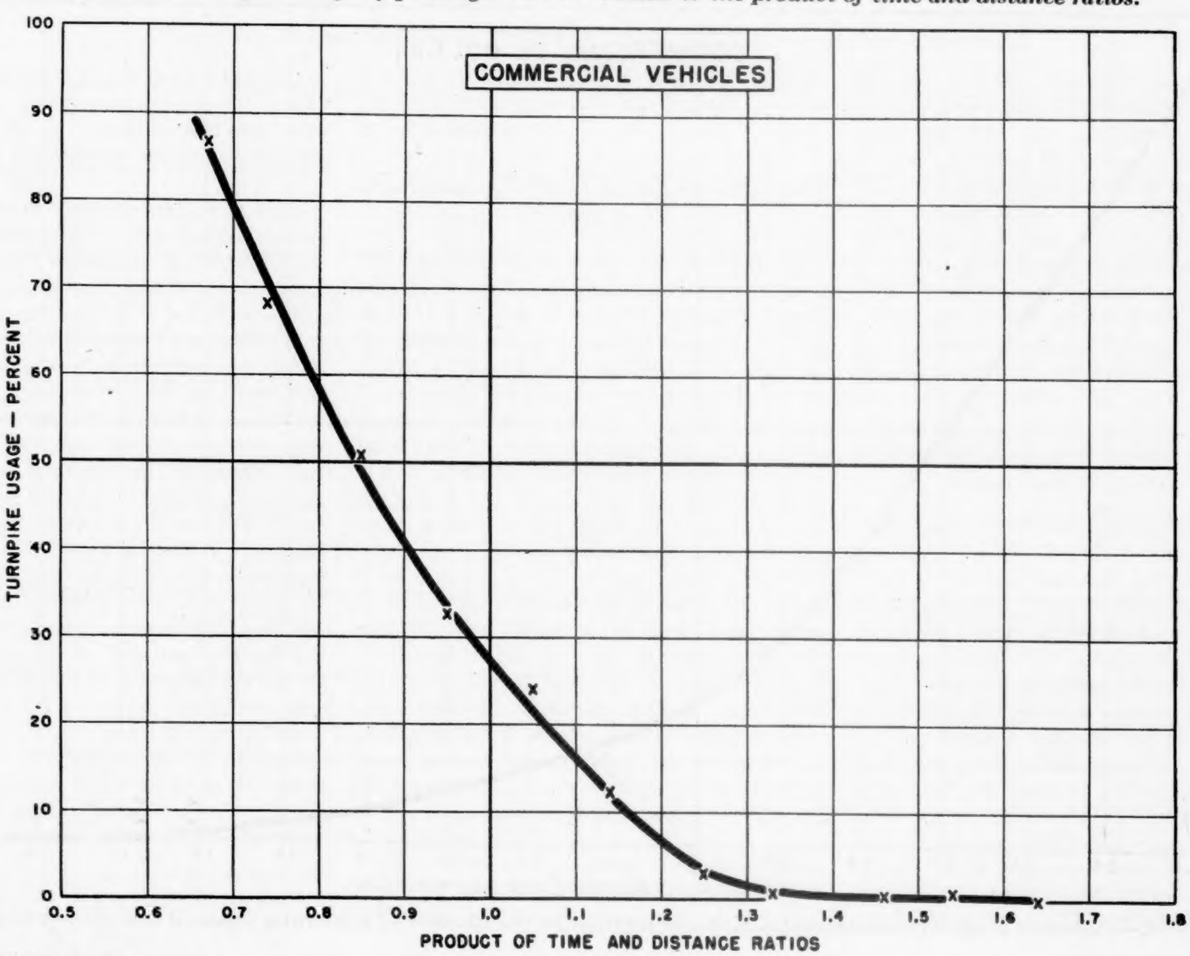


Figure 13.—Turnpike usage by passenger cars in relation to the product of time and distance ratios.



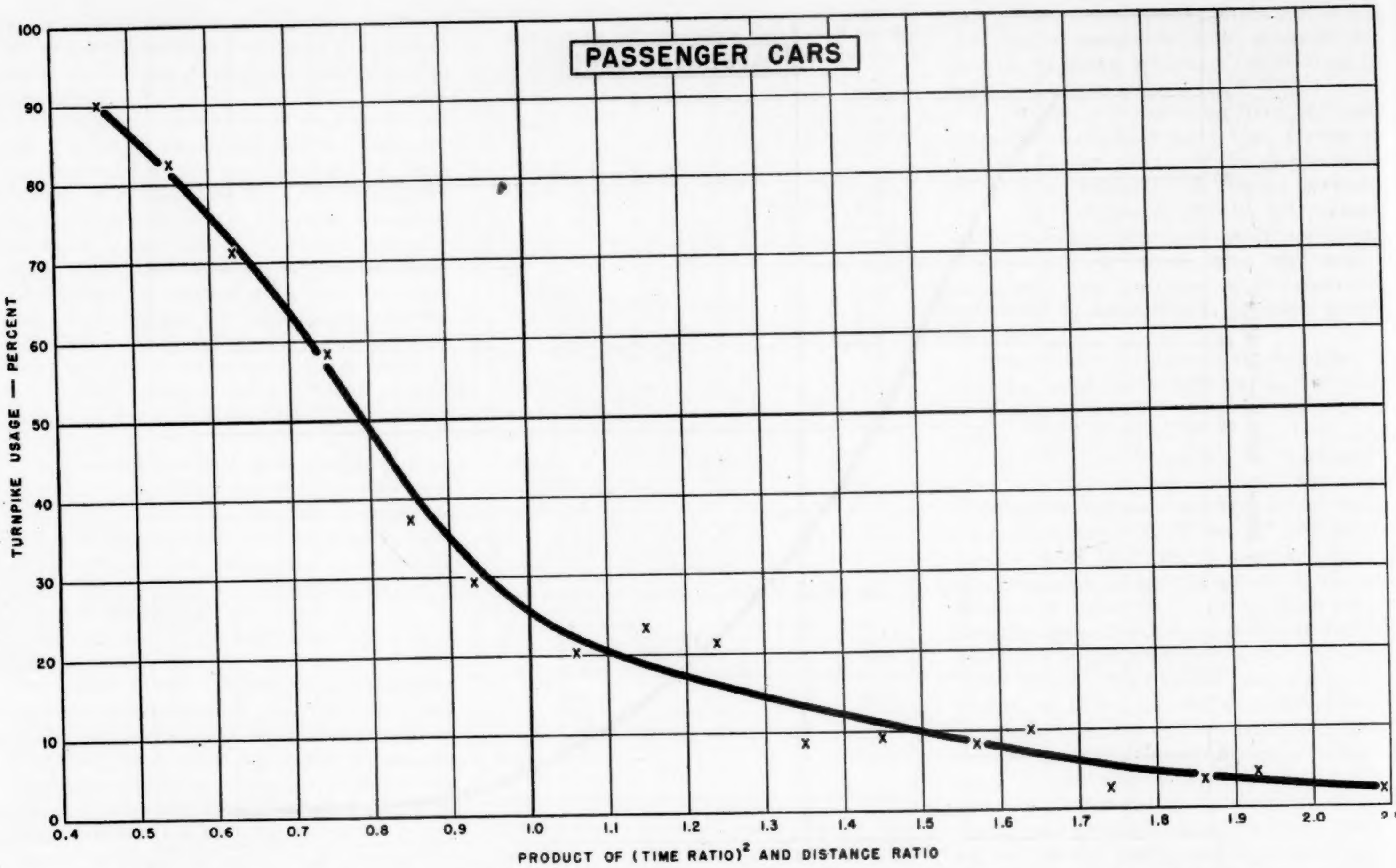


Figure 15.—Turnpike usage by passenger cars in relation to the product of time ratio squared and distance ratio.

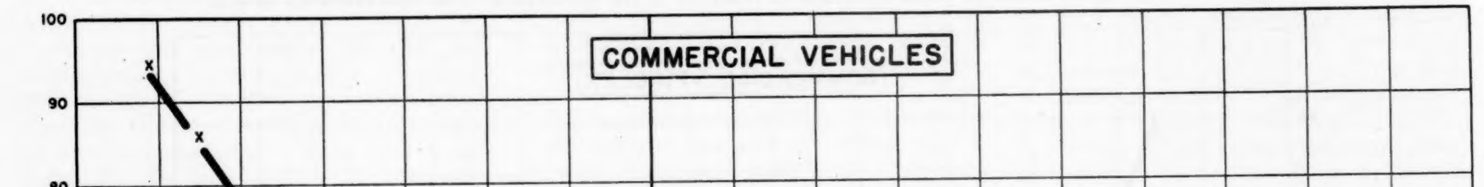


Figure 16.—Turnpike usage by commercial vehicles in relation to the product of time ratio squared and distance ratio.

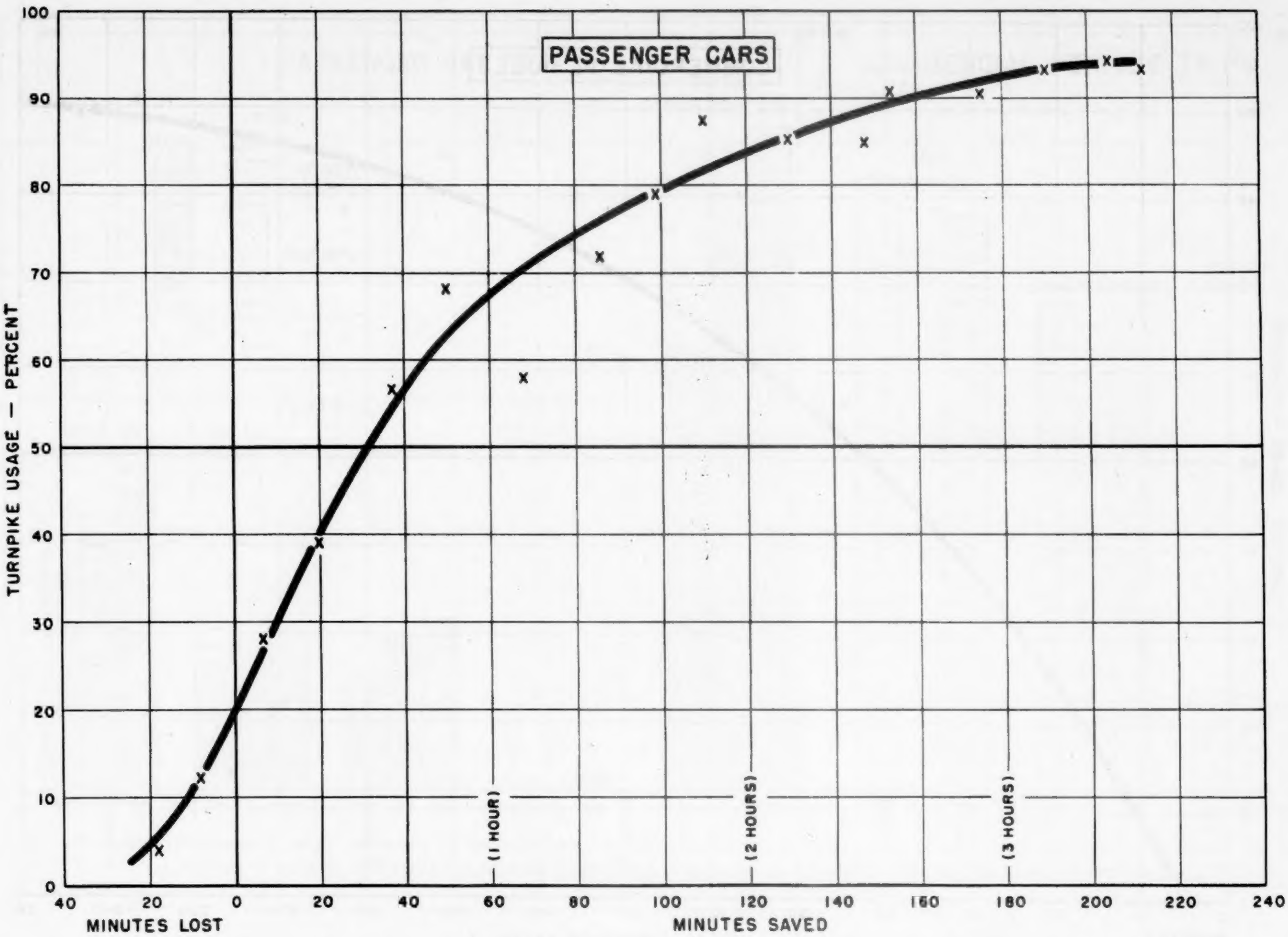


Figure 17.—Turnpike usage by passenger cars in relation to the time differential.

The percentage use for commercial vehicles is much less than that for passenger cars as the time ratio increases to 0.80 and above, with only one-third as much as for passenger cars at a ratio of 1.05.

A comparison of turnpike usage with that of a free road of similar design is valuable because it may give some indication of the effect of tolls on the usage of such a facility. A curve showing the percentage use of a portion of the Shirley Memorial Highway, a free fully controlled-access road in Virginia entering Washington, D. C., was developed in a previous study.[5] If the curve developed for the Shirley Highway had been applicable to the Pennsylvania Turnpike, 62 percent of the eligible trips would have been made on the facility, whereas only 44 percent actually did so. In other words, approximately 70 percent of the trips that would have been made on such a free road had the Shirley Highway curve been applicable, actually were intercepted on the turnpike and paid toll. We cannot conclude that this percentage is an accurate measure of the effect of the toll charge on turnpike usage, however, as there are other important differences between the two highways. The Shirley Highway is shorter and has more frequent interchanges than the Pennsylvania Turnpike. Even more important, perhaps, is the fact that it is located largely in an urban area, whereas the area through which the turnpike passes is dominantly rural.

[5] *The effect of travel time and distance on freeway usage,* by Darel L. Trueblood. PUBLIC ROADS, vol. 26, No. 12, Feb. 1952.

Turnpike Usage Related to Distance Ratio

Distance ratios were computed in a manner similar to that for time ratios already described except that distances were substituted for time. For trips extending beyond the turnpike limits, distance ratios were computed from point of choice, as in the case of time ratios. Turnpike usage in relation to distance ratios for passenger cars is shown in figure 11.

Few of the distance ratios in Pennsylvania are less than 1.00. Where the distance is the same, a very large percentage of vehicles will be found on the turnpike, since in such case there is a substantial saving in time. In fact, at a distance ratio of 1.00 and at a time ratio of 0.79, about 73 percent of the passenger cars in Pennsylvania, on the average, used the turnpike. As in the case of the time-ratio chart (fig. 9), the distance-ratio chart has critical areas where the scatter is rather large when plotted for individual zone-to-zone trip interchanges, but by properly combining the data a logical series of points can be obtained to establish a curve.

The comments concerning distance ratios for passenger cars apply in general to commercial vehicles. However, for commercial vehicles, the shape of the distance-ratio curve (fig. 12) is more nearly like the time-ratio curve (fig. 10) than was the case for passenger cars. Of course, the values for distance ratio are greater. Where the distances are equal via the turnpike and via highways; i. e., ratio 1.00, about 68 percent of the total commercial vehicles used the turnpike. This is 5 points less than at the same distance ratio for passenger cars. There was a considerably lower percentage of commercial vehicles using the turnpike than in the case of passenger cars when the distance ratio was 1.25 or greater.

Turnpike Usage Related to Product of Time and Distance Ratios

In figure 13 is presented a curve indicating the turnpike use for the several values of the product of the time and distance ratios for passenger cars. This curve is less steep than either the time- or distance-ratio curves for passenger cars. The ratio ranges from less than 0.70 to more than 1.70 or almost twice the spread for the time ratio.

The turnpike usage as read from this curve amounts to about 90 percent at 0.68, which is practically the same as indicated by the time-ratio curve. However, at ratio 1.00, 36 percent instead of 19 percent used the turnpike. There was a 4-percent usage of the turnpike at product ratio 1.70, while for the time ratio this percent usage occurs at 1.16.

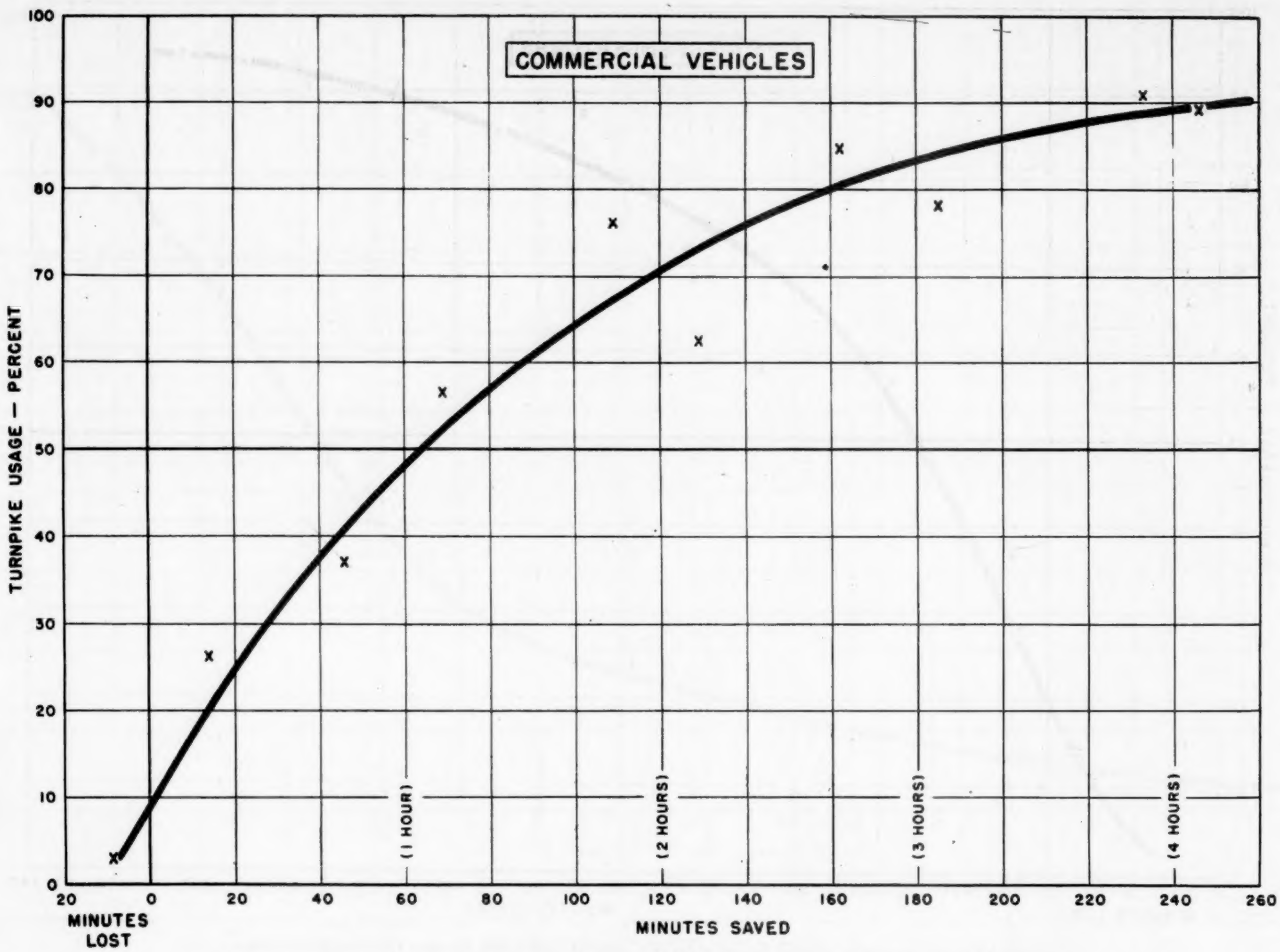


Figure 18.—Turnpike usage by commercial vehicles in relation to the time differential.

The curve for turnpike usage for commercial vehicles is shown in figure 14. This is somewhat similar to the passenger-car curve, but a little steeper. Also, the turnpike usage is almost nil after the ratio reaches 1.35, whereas the passenger-car curve still shows 4-percent usage at 1.70.

The difference in turnpike usage between the two curves is about 13 percentage points at 0.80 and 4 points at 1.60 and above. At 1.00 ratio 27 percent of the commercial vehicles used the turnpike as compared with 36 percent for passenger cars. At 1.00 the difference is, therefore, 9 percentage points, but this is equivalent to 33 percent more passenger cars than commercial vehicles.

Usage Related to Product of Time Ratio Squared and Distance Ratio

The product of time and distance ratios has a tendency to flatten the curve in comparison with either time-ratio or distance-ratio curves. Time ratio may be more indicative of turnpike usage than distance ratio, since the distance ratio between two zones remains constant while the time ratio may vary for the same zones from time to time because of changes in speed. For example, the time ratio may be reduced with consequent increase in turnpike use when the parallel free road becomes congested to the extent that driving time is increased thereon.

This being true, it was thought that assigning more weight to the time ratio might improve the curve based on the product of time and distance ratios. After much experimenting, it was found that the square of the time ratio multiplied by the distance ratio ($T^2 \times D$ ratios) gave good results. Such a curve is shown in figure 15 for passenger cars. The range in ratios is from less than 0.50 to over 2.00, or almost 3 times the range for time ratio (fig. 9).

The curve for commercial vehicles, figure 16, is quite similar to the one for passenger cars but, as usual, the commercial usage of the turnpike is less than for passenger cars for the same ratio. The commercial-vehicle curve ranges from less than 0.40 to 1.90. Actually the turnpike usage becomes practically zero at 1.70 and above. The passenger-car curve shows 2 percent use of the turnpike at 2.10.

At ratio 1.00, more than 25 percent of the passenger cars use the turnpike, while only 17 percent of the commercial vehicles do so for the same value.

Usage Related to Time Differential

The curve showing turnpike usage on the basis of time saved or lost for passenger cars is shown in figure 17. Like all of the usage curves, there was considerable scatter when individual zone-to-zone movements were used. By grouping into 15-minute intervals the data became sufficiently well stabilized so that a smooth curve could be drawn. With smaller time groupings, a number of points were considerably out of line, but for portions of the curve where this was not the case they were sometimes used to aid in determining the exact shape of the curve.

It will be noted that some trips were made on the turnpike even with a 20-minute loss in time, which means a considerable loss in distance. With a saving of 20 minutes, approximately 40 percent of the drivers paid toll in preference to using the regular highways; this percentage increases to over two-thirds of the trips with an hour's saving in time, and to 93 percent with a 3-hour saving.

The minutes-saved curve for commercial vehicles is shown in figure 18. The scatter pattern for trucks is such that the groupings in number of minutes saved is double that for passenger cars (30 minutes instead of 15) before stability results.

For commercial vehicles the use of the turnpike was less than for the same time saving for passenger cars. For 20-minute time saving there was 25 percent usage for trucks compared with 40 percent for passenger

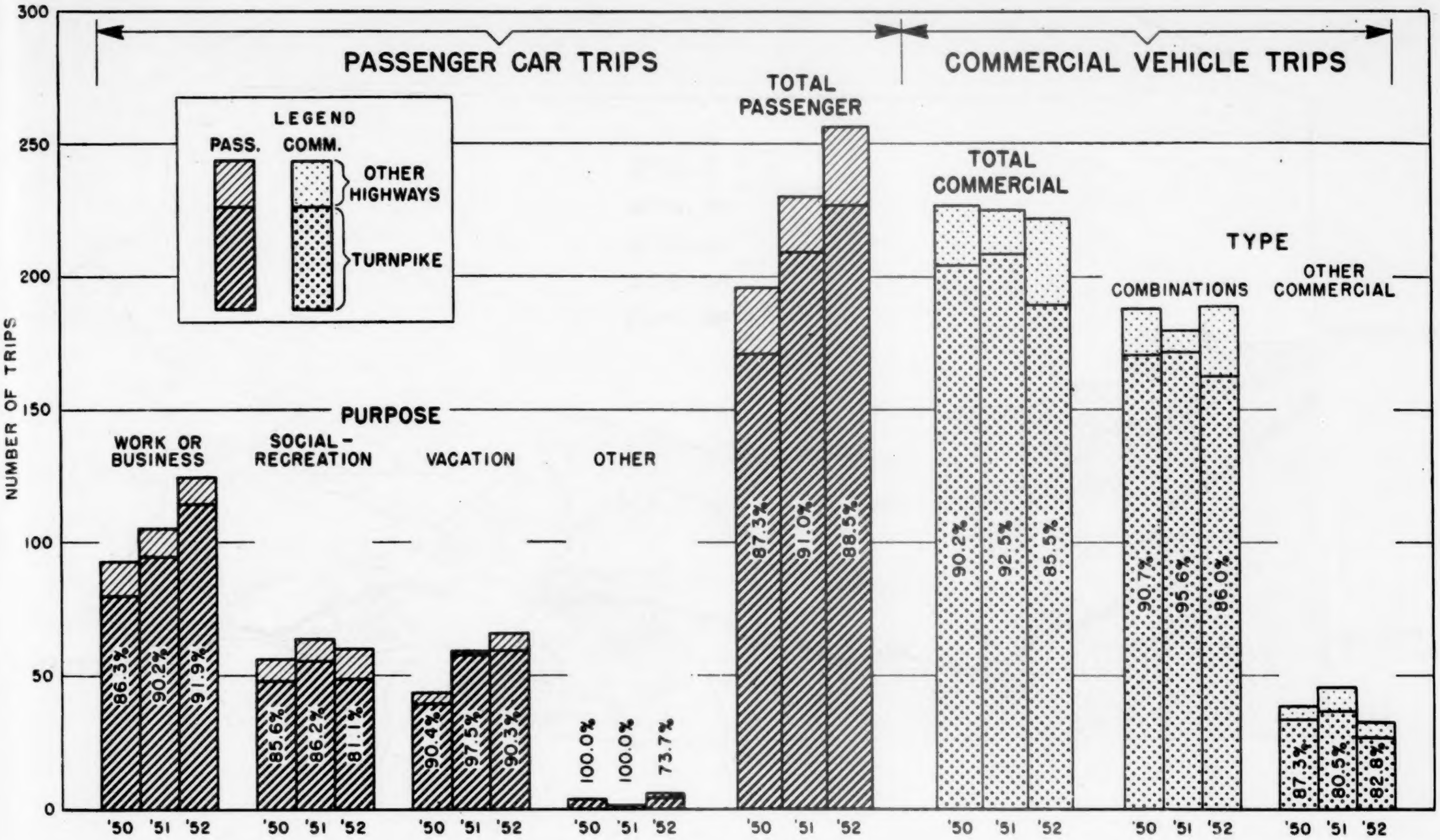


Figure 19.—Number of through trips between Pittsburgh and Philadelphia for passenger cars and commercial vehicles on an average summer weekday, related to turnpike usage and trip purpose (passenger cars) for years 1950–52.

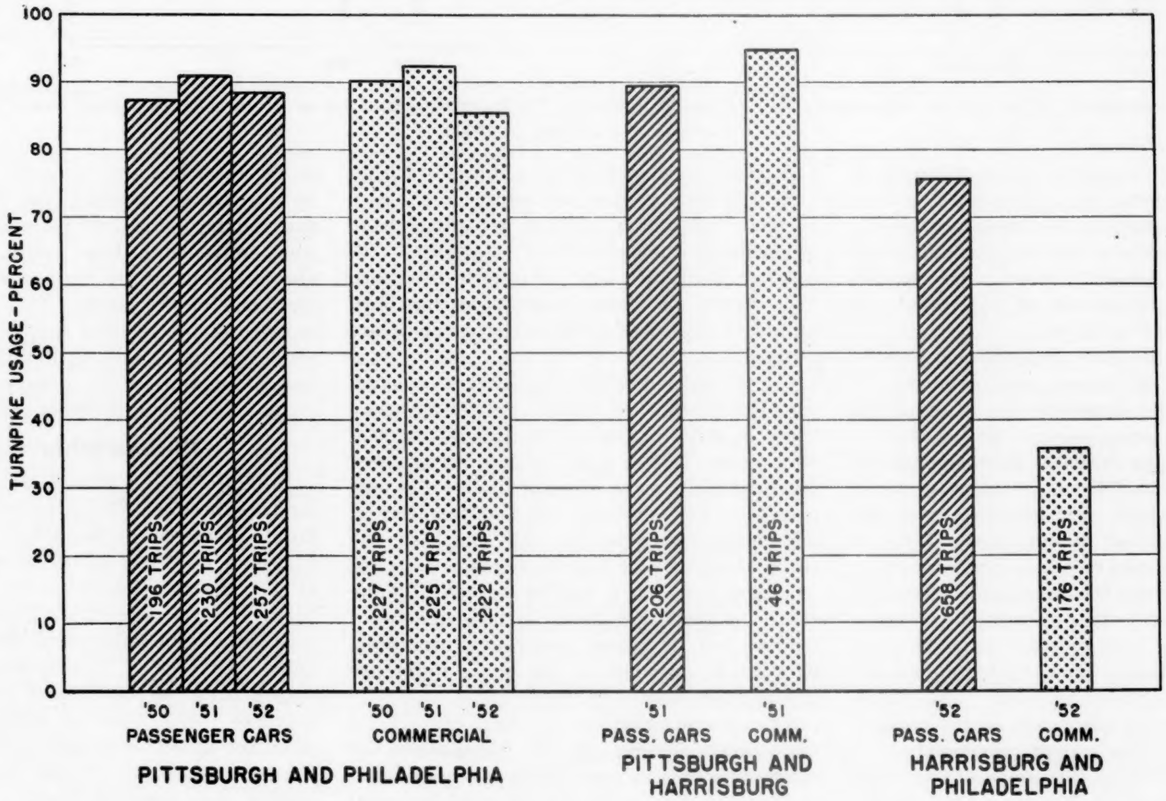


Figure 20.—Turnpike usage for through trips between selected cities on an average summer weekday.

cars; for 1-hour time saving, a 48 percent usage compared with 67 percent for passenger cars; for a 2-hour time saving, a 71 percent usage compared with 83 percent for passenger cars; and for a 3-hour saving, an 83 percent usage compared with 93 percent for passenger cars. No trucks losing 10 minutes or more used the turnpike.

Standard Error of Estimate

The standard error of estimate has been computed for each of the curves in this report

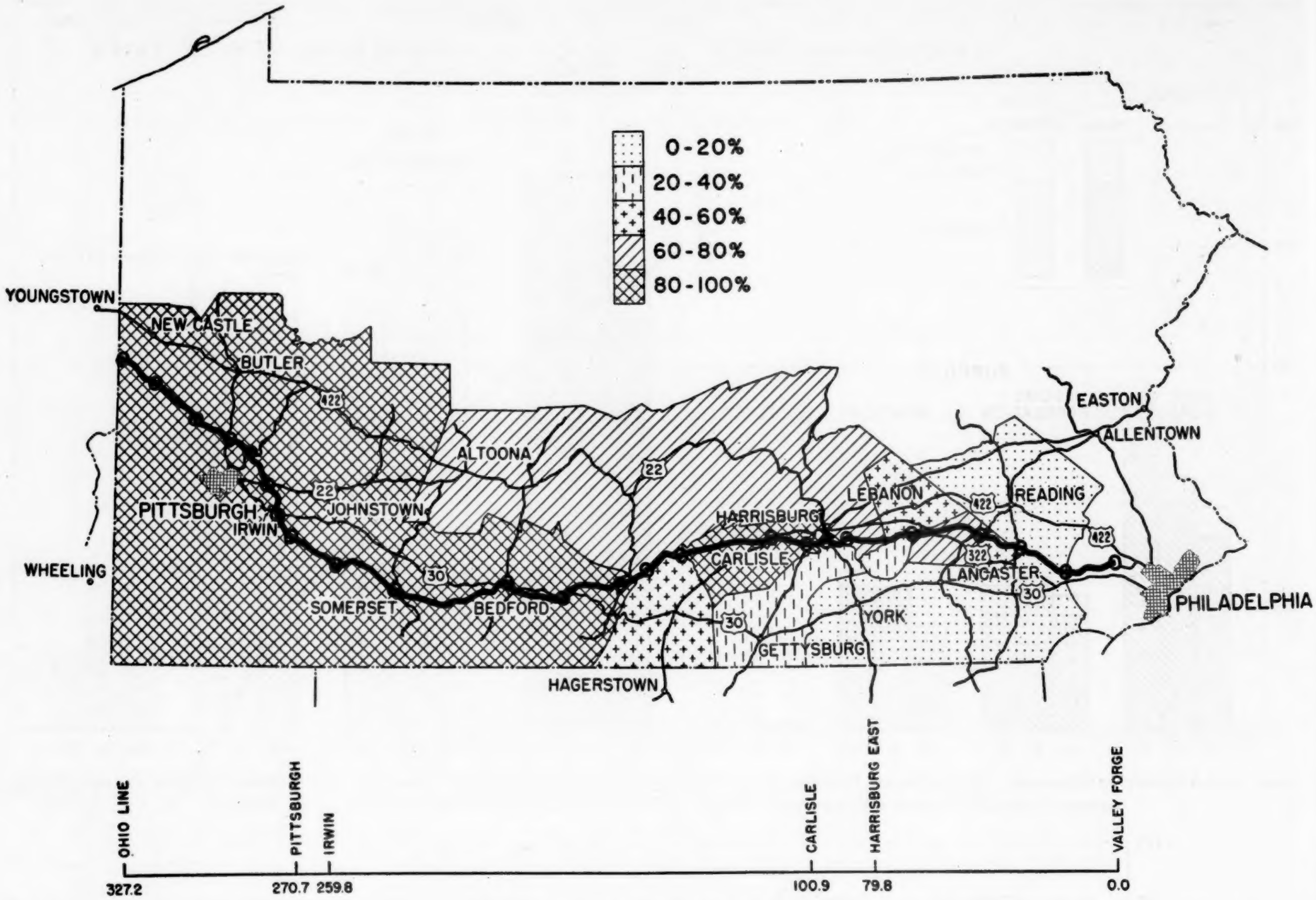


Figure 21.—Percentage of passenger cars using the turnpike between Philadelphia and areas along the turnpike route on an average summer weekday in 1952.

as a measure of the scatter of the averages of the grouped data from the fitted curve. Curves plotted parallel to a fitted curve and at a distance of plus or minus 1 standard error from it will contain within their bounds approximately two-thirds of the points to which the curve was fitted.

In general, original observations have a greater degree of scatter than averages for groupings of the observations. Computing group averages prior to curve fitting has the effect of smoothing the data. This is justifiable if thereby the functional relation is made apparent. However, care must be taken lest excessive smoothing obscure the effects of factors which should be taken into account.

In actual practice the origin and destination data are grouped in zone-to-zone movements. Unfortunately the trip interchange between zones is not uniform, varying from only a few trips to several thousand trips. The initial standard error was computed on the basis of the individual zone-to-zone movements notwithstanding the fact that some of the zone-to-zone trips were so few that they hardly constituted a sample of adequate size.

To mitigate the effect of the small sample, the data were then successively grouped into large units. In the case of ratio abscissa the trips within each 0.01 ratio were added together to give one point, then within each 0.05 ratio to give one point, and finally within each 0.10 ratio to give one point. In the case of time differential, similar groupings were successively made within 5-minute, 10-minute, 15-minute, and 30-minute intervals. The results of these calculations for both passenger cars and commercial vehicles are tabulated in table 3.

For the individual zone-to-zone movements, time differential has slightly greater accuracy than the other curves for both passenger cars and trucks. However, as the data are grouped the time-ratio curve appears to give the best results. In addition, time differential is inherently dependent on the length of the turnpike and would, therefore, require a series of curves for each length of turnpike. Time ratio, on the other hand, is independent of length and is more generally applicable, particularly in view of the small difference in standard error.

The computation of standard error is of importance mainly in the comparison of methods. In the application of the results, the interest lies in the accuracy of the total volume which will use a facility rather than in the accuracy of the individual zone-to-zone movements.

Since any estimate of total turnpike volume would involve a large number of zone-to-zone movements, the proportion the standard error of the total bears to the total volume would be substantially smaller than the proportions the standard errors of estimates of zone-to-zone movements bear to zone totals. In absolute amount the former would be larger than any of the latter. It is probable that the size of the relative sampling error of the total volume is well within the accuracy of present measurements of zone-to-zone movements and of predictions of trends.

Philadelphia Trips

In figure 19 and table 4 are presented data for trips between Philadelphia and the Pittsburgh metropolitan area for 3 years. The 1950 and 1952 trip information was obtained at the same locations in eastern Pennsylvania between Harrisburg and Philadelphia. The 1951 data were collected in western Pennsylvania just east of Pittsburgh in connection with a study of the western extension of the turnpike. The time of operation was the same for all three samples and represents a summer weekday. Though the 1951 information was obtained more than 150 miles from the nearest operation in the East, the Philadelphia-Pittsburgh trips were intercepted in both studies and the data should be comparable.

The similarity of the number of trips, the type of vehicle, the purpose of trips for pas-

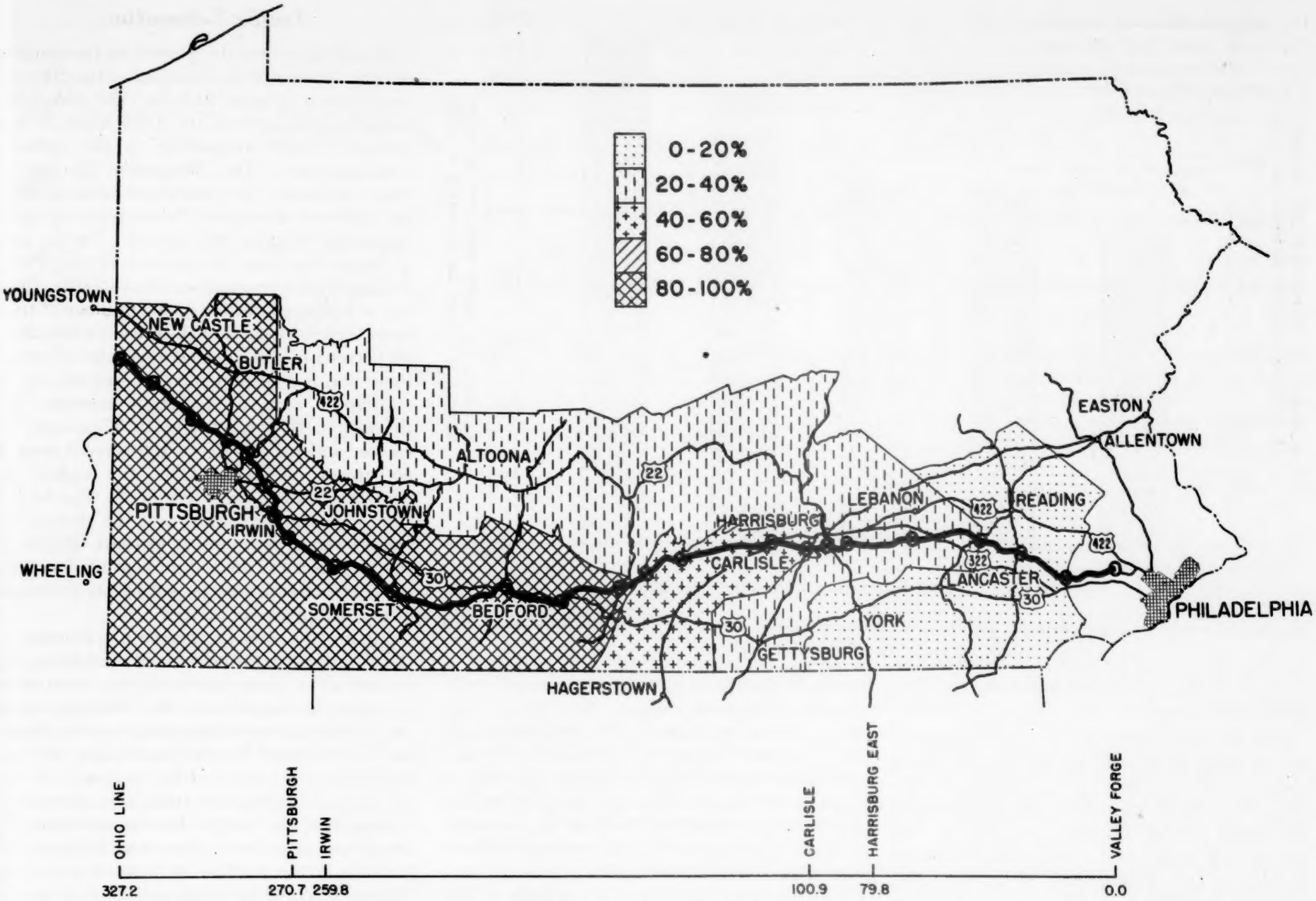


Figure 22.—Percentage of commercial vehicles using the turnpike between Philadelphia and areas along the route on an average summer weekday in 1952.

senger cars, and the percentage use of the turnpike in the several categories indicate the adequacy of the samples obtained in the three surveys. The number of passenger-car trips by purpose (work or business, social-recreation, vacation, and other) and the total trips for passenger cars and commercial vehicles with the latter divided into combinations and other commercial are shown in figure 19. The percentage of turnpike use by years for all purposes and for all types of vehicles is also indicated. A remarkable fact is that the average number of passenger-car trips between Philadelphia and Pittsburgh during the 3 years was almost exactly the same as the average number of commercial trips during the same period (228 and 225, respectively). However, passenger-car trips were increasing while commercial trips were decreasing. Also, about the same number of passenger-car and commercial-vehicle trips used the turnpike for the same 3 years (203 and 201, respectively). Trips for work or business and vacation increased steadily over the 3-year period, while those for social and recreation and for other purposes remained fairly constant. Turnpike usage by trips for work or business increased from 86 to 92 percent, but there was no apparent trend in turnpike usage by trips for the purposes in other categories. The high percentage use of the turnpike by passenger-car and commercial-vehicle trips is evidently due to the very great saving in time for both passenger cars and trucks. There is a large saving of fuel for trucks, particularly on the original section of the Pennsylvania Turnpike between Irwin and Carlisle.

The percentages of passenger-car trips between Philadelphia and Pittsburgh made for each purpose were similar for 1950, 1951, and 1952. Trips for work or business were 47, 46, and 49 percent of the total for each of the 3 years, respectively; for social-recreation 29, 28, 23; for vacation 22, 26, 26; and for other purposes 2, 0.5, and 2.

In figure 20 and table 4 are presented data showing the differences in turnpike usage for trips between Harrisburg and Philadelphia as compared with trips between Pittsburgh and Philadelphia and Pittsburgh and Harrisburg. Vehicles in the latter two categories use the turnpike to a considerably greater degree than those between Harrisburg and Philadelphia. The Pittsburgh-Philadelphia trips are shown for 1950, 1951, and 1952; the Pittsburgh-Harrisburg trips are shown for 1951 only, because these trips were not intercepted in the 1950 and 1952 surveys which were confined to the eastern extension; and the Harrisburg-Philadelphia trips are shown for 1952 only, because this section of the turnpike was not open in 1950 when the first survey on the eastern extension was made.

While 36 percent of all truck trips were made on the turnpike between Harrisburg and Philadelphia in 1952, only 23 percent of the combination vehicles used it. The reason for the low turnpike usage by these large vehicles has not been determined.

In 1951, 49 percent of the total trips between Pittsburgh and Philadelphia were made by commercial vehicles while only 18 percent were by commercial vehicles between Pittsburgh and Harrisburg. In 1952, 46 percent of the trips between Pittsburgh and Philadelphia were by commercial vehicles compared with only 21 percent for the Harrisburg–Philadelphia trips.

It was found that there was greater turnpike usage between Harrisburg and Philadelphia than between Harrisburg and the areas around New York City and New England. This was expected since a part of the traffic used the shorter routes via U. S. 22, going northeast from Harrisburg rather than the longer one via the turnpike and Philadelphia.

Figure 21 shows the relative passenger-car turnpike usage by trips between certain areas along the turnpike and Philadelphia in 1952. The areas are marked by different types of shading, so drawn that the usage of the turnpike by passenger-car trips between each area

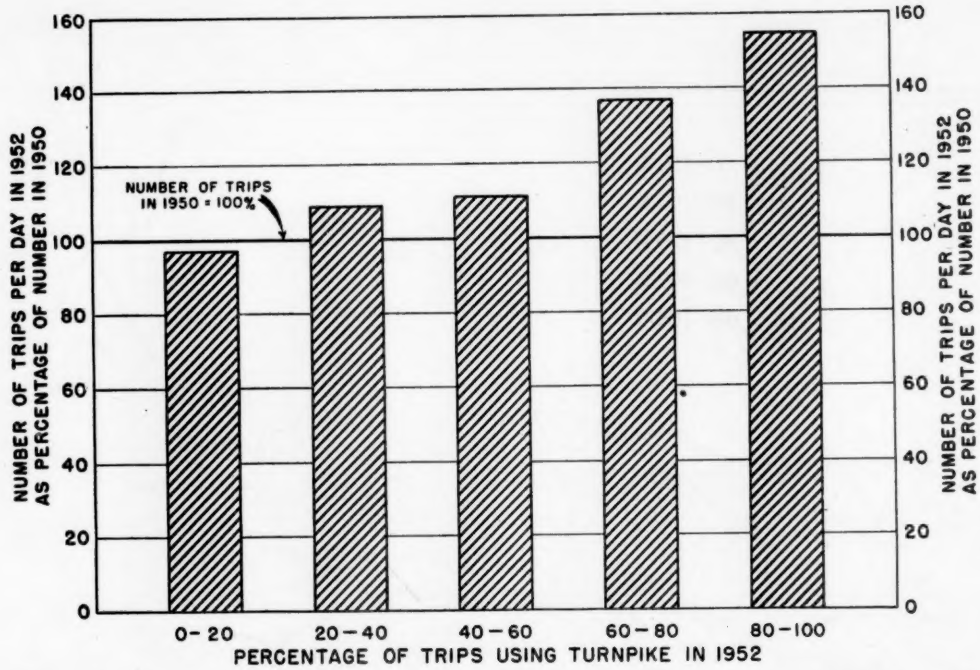


Figure 23.—Percentage change, 1950–52, in passenger-car trips between Philadelphia and areas of varying turnpike usage.

and Philadelphia falls within a specified percentage range.

Eighty to one hundred percent of the passenger-car trips with origin and destination in the area west of a point midway between Carlisle and Bedford were made on the turnpike. This area extends upward across U. S. 422 just west of Johnstown. Of the trips between Pittsburgh and Philadelphia, 89 percent were made on the turnpike.

There is another area of 80- to 100-percent usage extending westward from Harrisburg and including Carlisle. For passenger cars, 60 to 80 percent of the vehicles traveling between Philadelphia and areas along U. S. 22 from Harrisburg to Johnstown used the turnpike. The area where the usage was less than 20 percent extends from the Philadelphia end of the turnpike westward for about 40 miles and farther south, almost 100 miles westward along U. S. 30.

Figure 22 shows the relative turnpike use by commercial-vehicle trips in and out of Philadelphia in the same manner as passenger cars are shown in figure 21. The area where the turnpike usage was less than 20 percent was the same as that for passenger cars. The percentage of turnpike use for commercial vehicles in this area was very low in most cases, being 5 percent for Reading, 5 percent for Lancaster, and only 1 percent for York. Between Harrisburg and Philadelphia, 36 percent of the commercial vehicles used the turnpike compared with 76 percent of the passenger cars. The area to and from which 20 to 40 percent of the Philadelphia trips were over the turnpike includes Harrisburg and extends westward to the north along the route of U. S. 22 and U. S. 422 to a point north of Pittsburgh. This is in contrast with 60- to 80-percent usage by passenger cars for this area. South of the turnpike from Gettysburg westward, Philadelphia trips with origin and destination close to U. S. 30 were made via the turnpike to a rapidly increasing degree. The 80- to 100-percent area is reached at a point about half way between Carlisle and Bedford. Beyond that point over 80 percent of the commercial trips in the area served by U. S. 30 as the principal free route were made on the turnpike.

The high usage of the Pennsylvania Turnpike by commercial vehicles is unique in turnpike experience and is due principally to the very steep grades and sharp curves on U. S. 30.

Traffic Generation

Figure 23 shows the growth in the number of trips between Philadelphia and the different areas shown in figure 21 from 1950, before the turnpike was opened, to 1952 after it was opened. This comparison is for summer weekday trips. The 100-percent line on the chart represents the number of trips between the different areas and Philadelphia the year before the turnpike was opened. For the area in which less than 20 percent of the Philadelphia trips were made on the turnpike, there was a 3-percent decline in the number of trips from 1950 to 1952. For the area in which 20 to 40 percent of the vehicles used the turnpike, there was a 9-percent increase; for the 40- to 60-percent area, a 11-percent increase; for the 60- to 80-percent area, a 37-percent increase; and for the 80- to 100-percent area, a 55-percent increase. Thus, the higher the percentage use of the turnpike by trips to and from Philadelphia for any area the greater was the growth in the number of these trips after the turnpike was opened, indicating definitely that the increase was caused by the existence of the turnpike.

Figure 24 shows the percentage increase in the number of trips between Philadelphia and certain cities along the turnpike route after the turnpike was opened. For Reading, where the percentage use of the turnpike was 14 percent as indicated by the figure below the bar, there was only a 2-percent increase in the number of Philadelphia trips, as indicated by the height of the bar; for Harrisburg where the usage was 76 percent, there was a 53-percent increase in the number of trips to and from Philadelphia. For Carlisle and the intervening area west of Harrisburg, where there was an

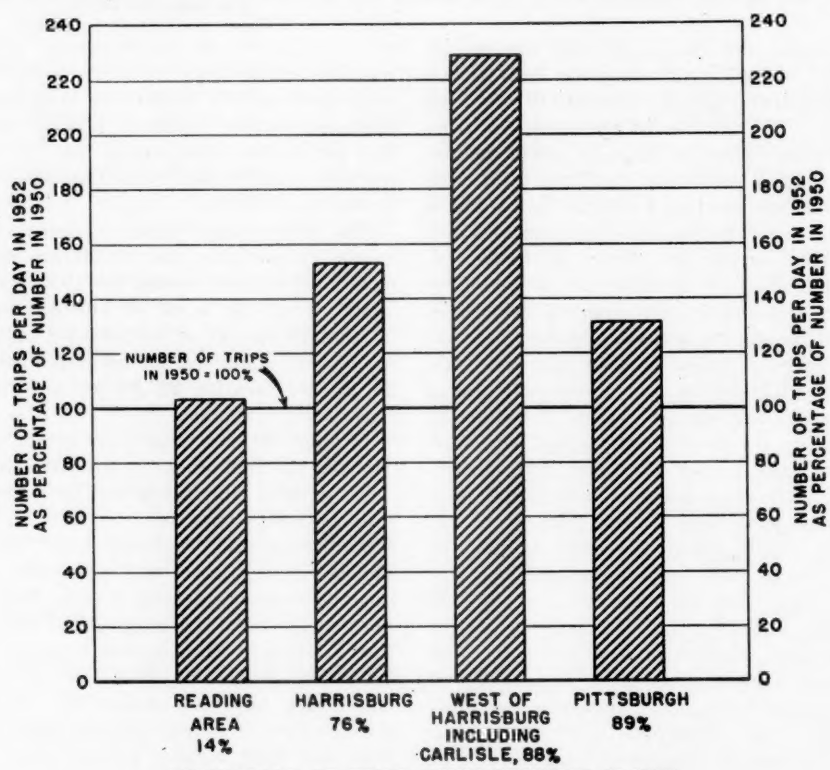


Figure 24.—Percentage change, 1950–52, in passenger-car trips between Philadelphia and cities along the turnpike.

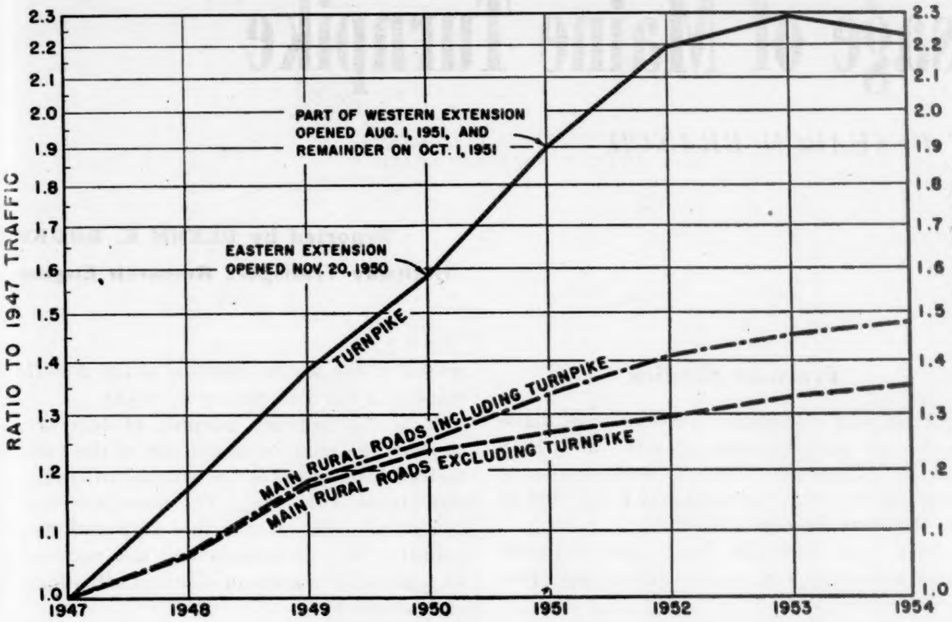


Figure 25.—Traffic growth on the original section of the turnpike (Irwin–Carlisle) compared with that on main rural roads in Pennsylvania, 1947–54.

88-percent usage of the turnpike for Philadelphia trips, the increase in the number of trips was 129 percent. This area is at the western end of the eastern extension of the Pennsylvania Turnpike and would, therefore, benefit more proportionately by the opening of the turnpike than any other area.

A number of these trips were undoubtedly new trips which would not have been made had not the turnpike been built, but some of them also were probably diverted from public carriers. Trips between Philadelphia and Pittsburgh have benefited by the existence of the original section of the Pennsylvania Turnpike from Irwin to Carlisle for many years, and the opening of the eastern extension was not so important, relatively, for these trips as it was for the trips between Carlisle and Philadelphia. For this reason, the percentage increase in the number of trips from Pittsburgh to Philadelphia after the opening of the eastern extension of the turnpike was only 31 percent.

From traffic counts before and after the opening of the turnpike, an attempt was made to estimate the total traffic generated between interchanges 19 (Harrisburg East) and 20 (Lebanon). It would appear that about 40 percent of the traffic on the turnpike between these interchanges was composed of new trips induced by the facility. However, some of these trips may have been diverted from routes so far away that they were not included in the study. In attempting to estimate traffic generation from counts alone, this uncertainty is always present.

Turnpike Traffic Growth

Figure 25 shows the growth from 1947 to 1954 of traffic on the original section of the Pennsylvania Turnpike between Irwin and Carlisle compared with that of other main rural roads in Pennsylvania, and all main rural roads including the eastern and western extensions of the turnpike during this same period. This figure is plotted on semilogarithmic paper, which has the characteristic of presenting equal rates of growth as parallel lines regardless of the height of the curve on the chart. Throughout the period from 1947 to 1952 the turnpike curve has a steeper slope than the curve for the other roads, indicating a more rapid growth. From 1952 to 1953 the two curves are very nearly parallel, and from 1953 to 1954 the turnpike curve drops, while the curve for other main rural roads continues to rise. This drop in traffic, 2.5 percent, on the old section of the turnpike in 1954 was largely due to a decline in truck usage of 6.4 percent, since passenger-car usage remained practically the same. Probably this is related to general economic conditions, there being a slight decline in the Gross National Product from 1953 to 1954.

The old section of the turnpike had been in operation for 7 years in 1947 so the more rapid growth of the turnpike traffic up to 1952 does not represent generation occuring soon after the opening of a new facility of this kind. There is no way of knowing whether it represents continuing generation or increasing diversion. The very steep slope of the turnpike curve from 1950 to 1952 undoubtedly shows the effect of the opening of the eastern and western extensions. The former was opened in November 1950 and the latter, partly in August and partly in December 1951. This is a good illustration of the effect of turnpike extensions and connections on traffic using the old section.

Figure 26 shows the growth of traffic on the old section of the Pennsylvania Turnpike throughout its life compared with that on other important rural roads in Pennsylvania, and on all rural roads including all sections of the turnpike. During the war years, traffic on the turnpike decreased much more rapidly than that on the other roads, but after 1944, the last full year of the war, it made a rapid recovery, and in 1954 it was 180 percent higher than in 1941, whereas traffic on other principal roads in Pennsylvania was only 26 percent, and including the turnpike, only 39 percent higher than in 1941. This exceptionally rapid growth of the Pennsylvania Turnpike traffic is probably due to unique features of this particular project and it would certainly be unwise to assume that such growth would be duplicated on other projects.

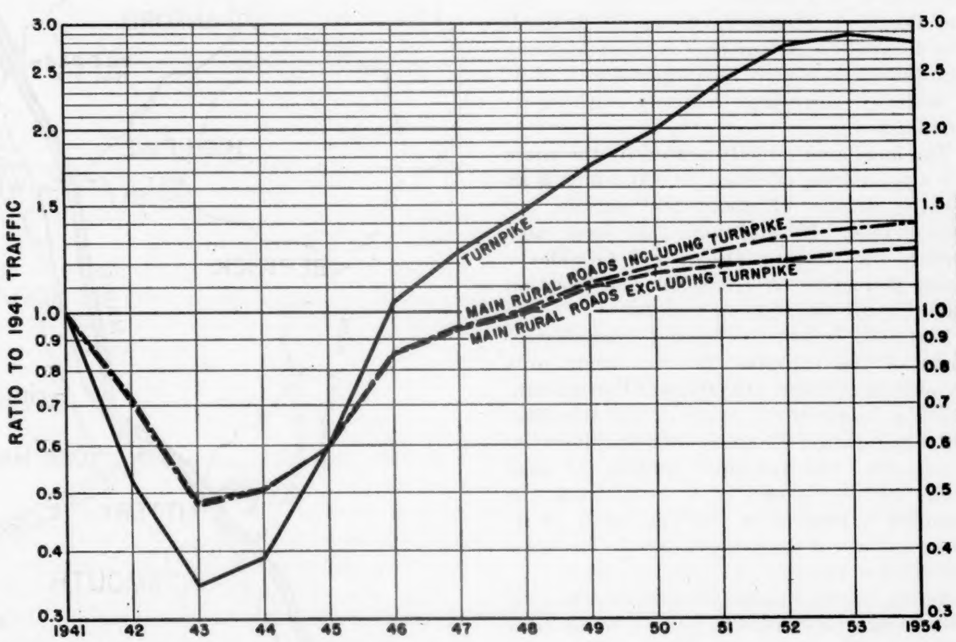


Figure 26.—Traffic growth on the original section of the turnpike (Irwin–Carlisle) compared with that on main rural roads in Pennsylvania, 1941–54.

Traffic Usage of Maine Turnpike

BY THE HIGHWAY TRANSPORT RESEARCH BRANCH BUREAU OF PUBLIC ROADS

Reported by GLENN E. BROKKE
Highway Transport Research Engineer

The Maine Turnpike was opened to traffic on December 13, 1947, as an alternate route to U. S. 1 between Kittery and Portland, Maine. Traffic was interviewed both before and after construction and continuous volume counts have been available since 1947.

This article shows the traffic growth, the State of registration of the vehicles, the repetitive frequency of trips on both highways, and the effect of these variables on the proportion of traffic using the turnpike. An empirical curve of passenger-car traffic diverted to the toll road on the basis of time ratio is established and compared with similar curves for the Pennsylvania Turnpike and a free limited-access facility.

The effect of increasing the toll rate from $0.50 to $0.60 and subsequently to $0.75 for a full-length trip is investigated and related to the amount of traffic using the turnpike. The amount of traffic attracted by the construction of the new facility beyond that anticipated from normal increase is determined, and the distribution of the excess increase between the old road and the turnpike is reported.

THE Maine Turnpike, a 42.2-mile toll facility, provides an alternate route of travel to U. S. 1 between Portsmouth, N. H., and Portland, Maine, as shown in figure 1. The turnpike is a four-lane divided highway with full access control as compared to U. S. 1, a basically three-lane roadway with unrestricted access.

The local area directly served by the route has a population of about 64,000, which is an average density of about 200 persons per square mile. In addition, this local area borders the Atlantic Ocean and provides a strong attraction for recreation and vacation traffic during the summer months.

Portland, which is located immediately north of the turnpike, has an urban area population of about 115,000; and Portsmouth, which is immediately south of the turnpike, has a population of about 19,000. Between these cities the principal sources of local traffic are to the east of U. S. 1, while the turnpike is located to the west of U. S. 1. Thus, the use of the turnpike results in excess travel for a majority of the local trips.

Access to the turnpike is provided at four intermediate toll stations as well as at each terminal station. A fifth intermediate toll station between the Saco interchange and the north terminus is operated during the summer months.

Previous Studies

Origin and destination surveys were made in August and October of 1947 and 1948 and in August of 1950. Partial results of these surveys were presented at a meeting of the Highway Research Board.[1]

Data from both the Maine and Pennsylvania Turnpikes were combined in a paper presented at the annual meeting of the American Society of Civil Engineers in 1954.[2]

It is the primary purpose of this article to show the relative magnitude of the various factors that influence the amount of traffic on the Maine Turnpike. The data reflect conditions as they exist in this area and, consequently, the conclusions will not necessarily be applicable in areas of substantially different characteristics.

[1] *Proportionate use of Maine Turnpike by traffic through Portsmouth-Portland corridor*, by J C Carpenter. Proceedings of the Highway Research Board, vol. 32, 1953, pp. 452–463.

[2] *Traffic diversion to toll roads*, by John T. Lynch. Proceedings of the American Society of Civil Engineers, vol. 81, separate No. 702, June 1955.

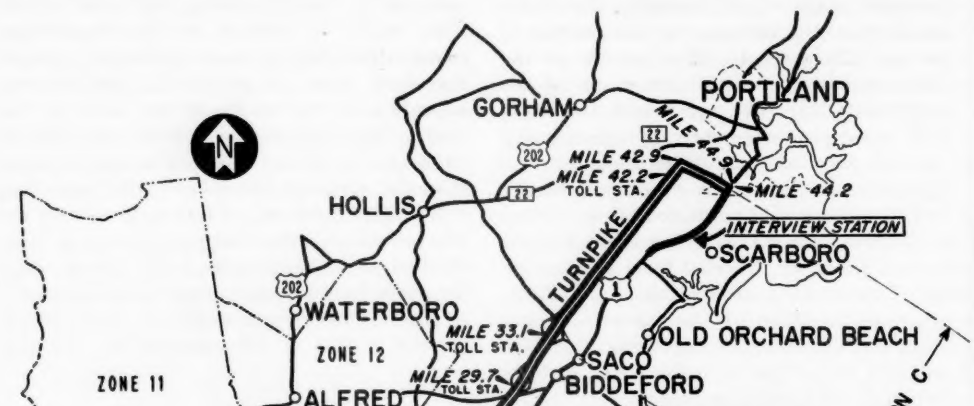


Figure 1.—Sketch of the Maine Turnpike corridor.

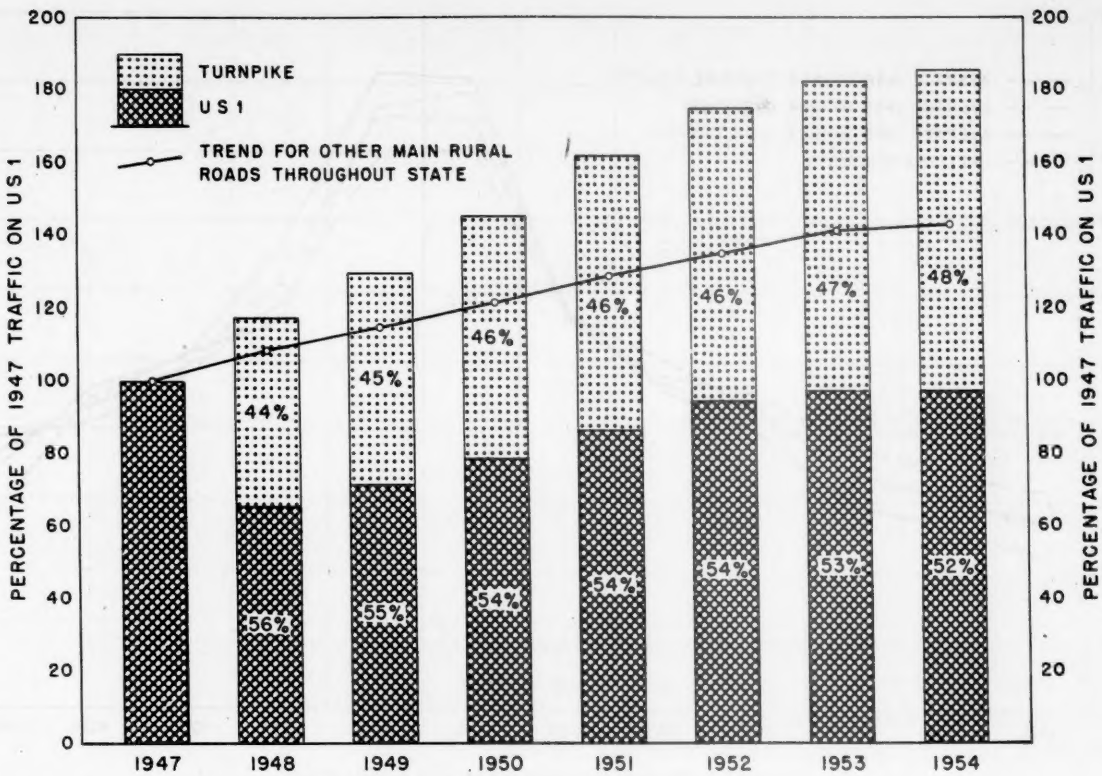


Figure 2.—Traffic using the Maine Turnpike as related to parallel route U. S. 1 at Mile 29 for years 1948–54, as compared with 1947.

Conclusions

To determine accurately the amount of traffic that will be attracted to a new facility, it is necessary to obtain information concerning the origin and destination of trips and relative speeds on the existing highways as compared to the new facility. It has been found that the most accurate single measure of traffic diversion is time ratio; that is, the time required to make a trip on the improved facility divided by the time required to make it by the existing route.

For preliminary purposes, rough estimates of the proportion of the traffic which would use a new facility can be made on the basis of less comprehensive field information, particularly if most of the potential traffic consists of diversion from an adjacent parallel route. Formulae for relating both traffic volume and State of vehicle registration to turnpike usage are developed in this article.

These approximate measurements might serve to determine whether a proposed project has sufficient merit to justify further examination by means of a study of the origins and destinations of the potential traffic.

The traffic served by a new limited-access facility and the old parallel highway is the existing traffic multiplied by a normal increase factor and further multiplied by a generation factor. In the case of the Maine Turnpike and parallel U. S. 1, the generation factor increased at approximately 6 percent a year for 5 years, after which it remained constant at approximately 1.30.

In the case of Maine, origin and destination data obtained from screen lines at both ends of the proposed turnpike would have accounted for 99 percent of the traffic using the turnpike.

Table 1.—Average daily traffic volume for the Maine Turnpike and parallel route U. S. 1 for the years 1948–54

Year	Average daily traffic for—			Percent of traffic using turnpike
	U. S. 1	Maine turnpike	Total	
1948	4,194	3,321	7,515	44.2
1949	4,577	3,719	8,296	44.8
1950	5,033	4,252	9,285	45.8
1951	5,551	4,809	10,360	46.4
1952	6,039	5,144	11,183	46.0
1953	6,222	5,438	11,660	46.6
1954	6,229	5,653	11,882	47.6

From the origin-destination data, the present and estimated future trips can probably be assigned to a toll road from the Maine Turnpike or Pennsylvania Turnpike curve or an interpolation between the curves.

The time-ratio curves appear to be applicable for toll rates up to at least 1¾ cents per passenger-car mile.

Traffic Growth

Figure 2 shows the trend in traffic on U. S. 1 and the Maine Turnpike from 1947 (the last year before the turnpike was opened) through 1954. The U. S. 1 traffic data used in this comparison were recorded near the middle of the Maine Turnpike area where the volume was lowest, in order to eliminate as much as possible the effect of local traffic which could not conveniently use the toll road.

In figure 2, the 1947 traffic volume on U. S. 1 is assigned the value of 100. The line sloping upward on the chart represents the trend of traffic on other important routes throughout Maine in relation to 1947 traffic. The height of the individual bars represents the total amount of traffic in each year. The shading of the bars denotes the portion of the traffic that used U. S. 1 and the turnpike. Figures within the shaded portions indicate the percentage of total traffic that used each of these facilities.

Traffic Diversion Related to Corridor Volume

Figure 2 indicates the most simple measure of traffic diversion. If U. S. 1 and the turnpike are defined as the corridor, then for each value of annual traffic volume in the corridor, a percentage diversion to the Maine Turnpike can be determined. Table 1 shows the average daily traffic volumes for the Maine Turnpike and parallel route U. S. 1, and the percentage of traffic using the turnpike for each of the years, 1948–54. The data essentially represent a straight line indicating a basic diversion of 39 percent to the turnpike, plus 1 percent for every 1,400 average daily traffic in the corridor. This relation may be expressed as follows:

$$\text{Percentage diversion to turnpike} = 39 + \frac{\text{ADT}}{1{,}400}$$

In order to compare the Maine Turnpike with other limited-access highways, it is desirable to take into account the surfaced width of the highway from which traffic is being diverted. U. S. 1 has an average width of 32.8 feet. Thus, the figure 1,400 for average daily traffic can be interpreted as approxi-

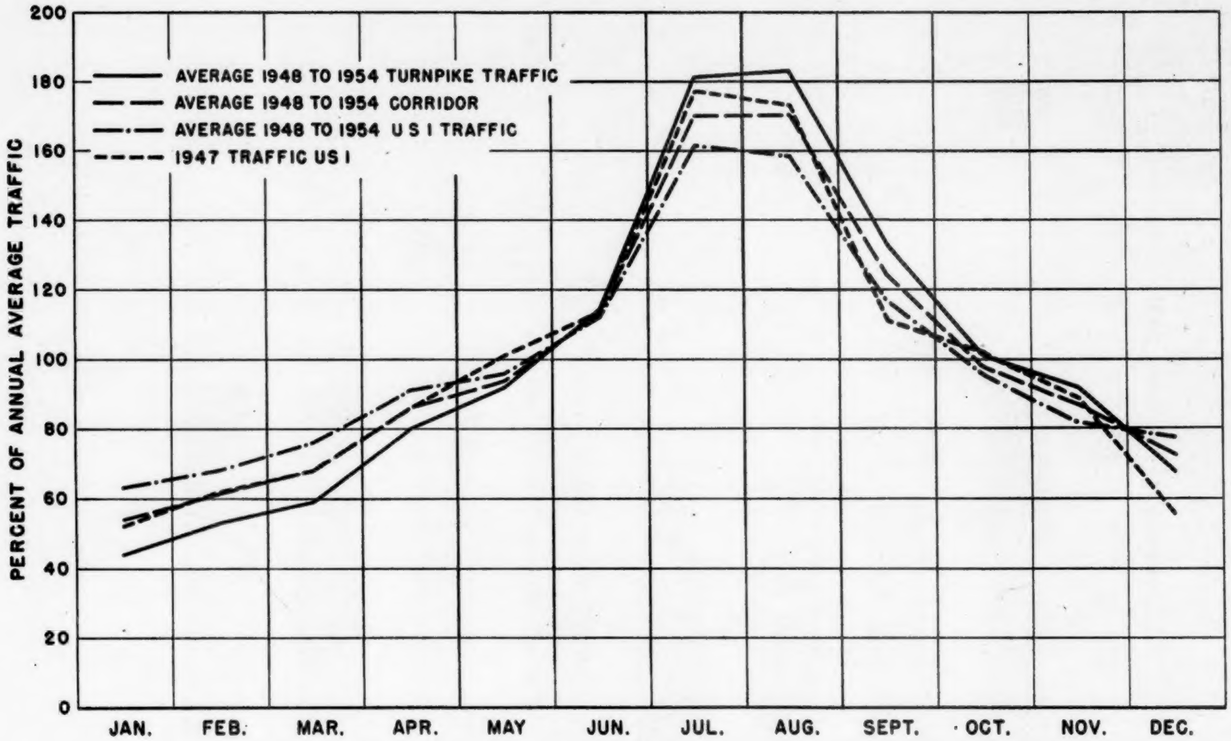


Figure 3.—Monthly variations in the traffic flow.

mately 425 ADT per 10-foot lane. The percentage diversion on a volume basis can therefore be more generally stated as:

Percentage diversion to turnpike=

$$39+\frac{\text{ADT per 10-foot lane}}{425}$$

Inasmuch as the Maine area attracts resort travel, the summer season has a much higher traffic volume than the remainder of the year. The magnitude of this variation is shown in figure 3.

It is of interest to note that generally during those months in which the corridor is carrying more than the annual average volume, the turnpike is carrying relatively more traffic than U. S. 1. Conversely during the months of less than annual average volume, U. S. 1 is carrying relatively more traffic. The seasonal fluctuations in traffic on U. S. 1 have been reduced somewhat by the construction of the turnpike, because the latter provides needed relief during peak flow.

The percentage of the total traffic that is diverted to the turnpike for each month of the year was computed, thereby establishing a percentage diversion for a wide range of traffic volumes. The individual months for the 7 years following the turnpike opening provided 84 plotting points for determining a curve relating percentage diversion to traffic volume. Naturally there was some scatter to these points, but the use of a series of moving averages resulted in a very smooth curve. The plotted points and the curve are shown in figure 4. In addition, figure 4 shows the line, previously discussed, representing the percentage diversion for the average daily traffic volumes in the different years. The plotted points from which this line was established are also shown.

The curve for the monthly traffic volumes departs substantially from the straight line for the annual average figures, although the curves are reasonably close for the corridor volumes in which they overlap. The reason that the curve for monthly traffic volumes diverges downward from the line for annual traffic volumes is probably that low volume counts occur during the winter when travel is predominantly local, while the high volume months are in the summer when there is a substantial volume of out-of-State traffic. Thus, it is likely that the percentage of foreign vehicles (out-of-State) influences the percentage diversion to the turnpike.

As a matter of interest, the diversion percentages for the first 2 years' operation of the Oklahoma Turnpike are also plotted in figure 4. These two points are somewhat above the Maine Turnpike curve which indicates a larger diversion percentage. Part of this excess diversion is probably attributable to attraction from more distant routes. However, figure 4 indicates that a percentage diversion based on volume does provide a rough approximation of the traffic on a toll road.

States of Registration

Table 2 shows the percentage of passenger cars using both U. S. 1 and the Maine Turnpike according to the States in which the vehicles are registered. From this table it is evident that foreign passenger cars use the turnpike in greater proportion than do local passenger cars. It is also evident that there is a material difference in usage by vehicles registered in the various States.

Passenger cars registered in New Hampshire show less tendency to divert to the turnpike than do passenger cars registered in Massachusetts. New Hampshire is adjacent to the south end of the turnpike while Massachusetts is centered approximately 80 miles south of the Maine Turnpike. However, vehicles registered in States more distant than Massachusetts have only a slightly higher tendency to divert and, as a matter of fact, passenger cars registered in States more than 500 miles

Table 2.—Passenger-car traffic on both U. S. 1 and the Maine Turnpike according to State of registration

State of registration	August 1948		October 1948 [1]		August 1950	
	Percent of corridor traffic	Percent using turnpike	Percent of corridor traffic	Percent using turnpike	Percent of corridor traffic	Percent using turnpike
Maine	33.4	32	59.7	32	37.7	38
Massachusetts	31.5	62	20.1	75	32.0	62
New York	8.2	55	2.8	78	6.4	54
New Hampshire	6.6	35	5.6	53	6.5	42
Connecticut	3.9	66	2.9	80	3.6	67
New Jersey	3.1	65	1.3	80	2.6	60
Pennsylvania	2.3	64	1.0	73	2.0	57
Rhode Island	2.2	60	1.3	79	2.3	59
Vermont	.5	37	.3	47	.5	38
All other	8.3	52	5.0	64	6.4	48
Total	100.0	49	100.0	48	100.0	50

[1] Weekday traffic only.

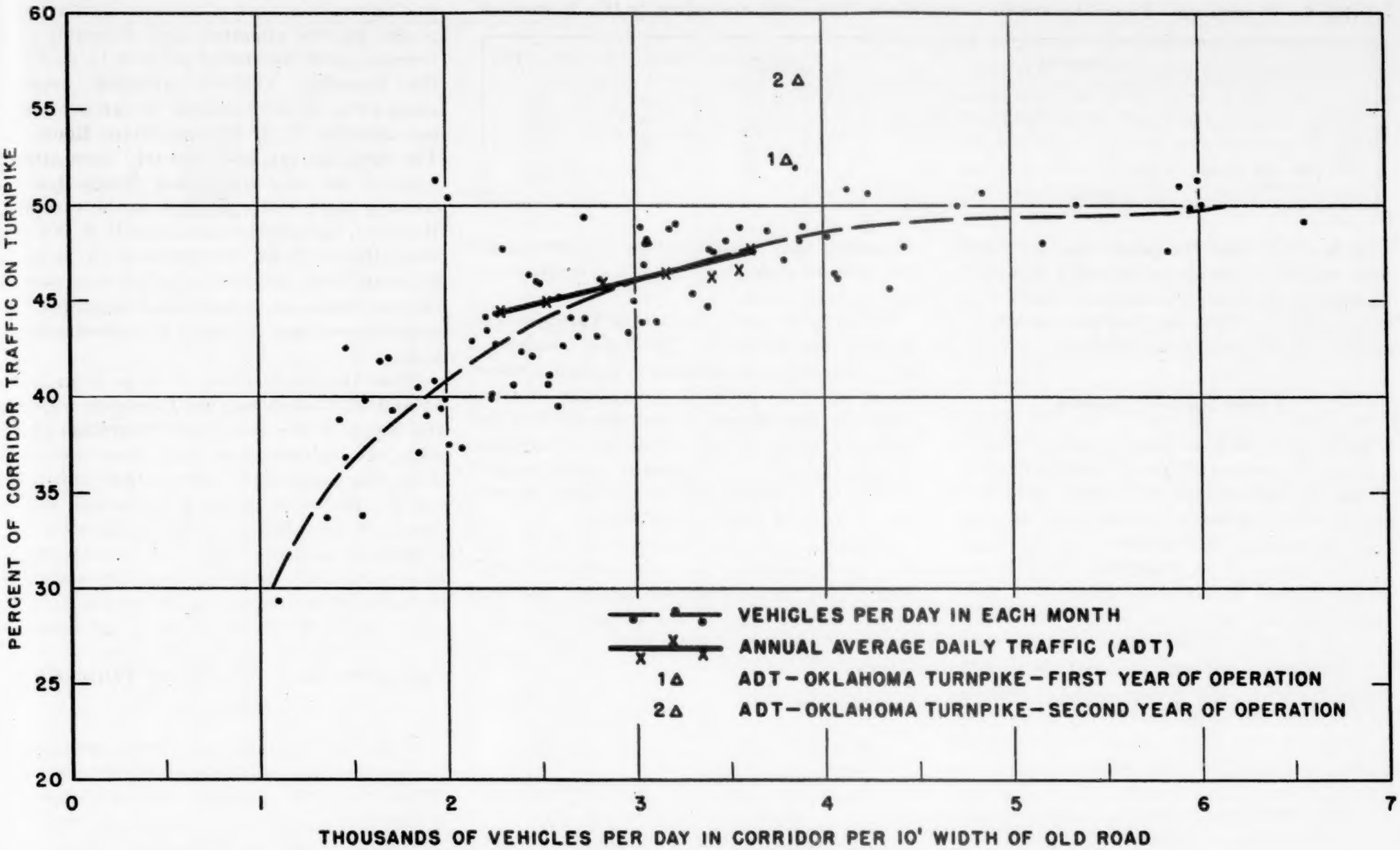


Figure 4.—Percentage of traffic diverted to the Maine Turnpike as related to total traffic volume in the corridor.

away appear to have slightly less tendency to divert than do vehicles registered in Massachusetts.

In addition to distance, the location of the State relative to the general axis of the turnpike appears to influence the diversion percentage. For example, Vermont is about the same distance from the turnpike as Connecticut, yet approximately one-half the percentage of Vermont cars use the turnpike as compared with Connecticut cars. In this connection it is noted that Vermont is located approximately at right angles to the turnpike while Connecticut is almost in line with the turnpike.

Finally, it is also evident that the diversion percentage of foreign traffic is dependent on the season of the year. Presumably many of the foreign cars, particularly from the more distant States, spend an appreciable amount of time in the turnpike area and become, in effect, local cars for the duration of their visit.

A mathematical expression which takes into account the factors mentioned and which approximates the diversion to the turnpike is as follows:

During resort season:

$$\text{Diversion} = \tfrac{1}{3} + \tfrac{1}{3} K \cos A$$

Where:

$K = 0$ for State of Maine.

$K = \frac{\text{Distance}}{100}$ for distances between 0 and 100 miles.

$K = 1$ for States more distant than 100 miles.

$A =$ Angle to the center of population of the State from general axis of turnpike.

During other times:

$$\text{Diversion} = \tfrac{1}{3} + \tfrac{1}{2} K \cos A$$

Where:

K and A have the same significance as above.

While this formula may apply only in the case of the special situation of the Maine Turnpike, it may be worthwhile to test it in other areas to see whether the formula, or a modification of it, would be useful in making preliminary traffic estimates to determine whether a proposed project might be worthy of further investigation.

Trip Frequency

As traffic is stopped and interviewed, a number of other characteristics of the traffic can be examined in more detail. One of the general elements that will increase the understanding of traffic behavior is that of trip frequency. Motorists who make a trip through an area every day will likely be acquainted with the location and condition of the various alternate routes. The infrequent user is more likely to follow route markings or to rely on general conceptions of the desirability of various routes. The trip frequency of traffic in the corridor, as determined from the interviews, is shown in table 3.

It is of considerable significance that during the summer season well over half the traffic was making the trip annually or less frequently. Even in October these infrequent trips account for approximately one-third of the traffic. Generally speaking, a larger percentage of vehicles making infrequent trips would be expected to use the turnpike than would those making trips on a more frequent basis. The actual percentages are shown in table 4.

Table 3.—Trip frequency of traffic in the Maine Turnpike corridor

Trip frequency	1947		1948		August 1950
	August	October [1]	August	October [1]	
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Daily	15	23	10	18	7
Weekly	17	26	16	23	19
Monthly	10	17	12	18	12
Yearly	35	24	40	26	45
Less than once yearly	23	10	22	15	17
Total	100	100	100	100	100

[1] Weekdays only.

Table 4.—Percentage of corridor traffic using Maine Turnpike according to trip frequency

Trip frequency	August 1948	October 1948	August 1950
Daily	11	15	12
Weekly	31	34	29
Monthly	57	62	51
Yearly	61	80	65
Less than once yearly	54	33	49
Average	49	48	50

It is noted that the percentage use varies with frequency about as expected except for those trips which are less frequent than annual. Trip frequency, however, does provide a rather sensitive indication of turnpike use.

Time Ratio Studies

With origin and destination data available, it is possible to establish the traffic diversion to the turnpike based on distance and time factors. The distance between zones of origin and destination was measured from maps. Travel time on U. S. 1 and the turnpike was obtained from field measurements. A time-ratio value was computed as time required to drive from origin to destination via the turnpike divided by the time required via U. S. 1, except for trips with either origin or destination beyond the limits of the turnpike. For these longer trips, the time was computed from a point near the turnpike where the motorist must make a choice of either U. S. 1 or the turnpike. The time ratio was computed from this point of choice. Figure 5 shows the diversion of passenger cars based on time ratio.

Data for trips in August of 1948 and 1950 were used in establishing the time-ratio curve. From the 2-year traffic data, a measure of the reliability can be obtained by comparing the diversion in each year with the average diversion of both years.

The area served by the Maine Turnpike was divided into 31 zones. The total number of trips with origin or destination in each of these zones, together with the percentage of trips made on the turnpike, were established for 1948 and 1950. The diversion to the turnpike of trips for each zone varied from less than 3 percent in the local area to more than 70 percent in areas of surrounding States.

Assuming that the average of 1948 and 1950 data represents the most probable value of diversion, the standard deviation of diversion percentages for each of the 31 zones for each year and for the time-ratio curve is as follows:

	Standard deviation percent
1948 data	4.5
1950 data	3.4
Time–ratio curve	8.0

In examining each of the individual zones, it was noted that vehicles on trips from zones 11 and 12 (fig. 1) actually divert to the turnpike at a much higher percentage than anticipated from the time-ratio curve. A study of the highway network of the area indicates the reason for this apparent high diversion. Interviews were conducted on only U. S. 1 and the turnpike. Vehicles traveling between zones 11 or 12 and Portland (or farther north) can also use U. S. 202 and State Route 22. The turnpike can and probably does attract some of the trips from these routes thus increasing the number of trips on the turnpike. However, the trips remaining on U. S. 202 and State Route 22 are omitted from the sample. Since all of the diverted trips but only part of the total trips are included in the sample, the actual percentage diversion is understandably high.

Since the total volume of trips from zones 11 and 12 is small and the time-ratio curve is the result of the smoothed integration of all trips, the high diversion from these two zones does not materially affect the time-ratio curve. However, from a statistical standpoint, the trips from these zones contribute an inordinate amount of the standard deviation. If zones 11 and 12 are omitted, the standard deviation of the remaining 29 zones is 5.9 percent instead of the 8 percent for all zones.

Comparison With Other Time-Ratio Curves

While the time-ratio curve has an acceptable degree of statistical accuracy when used with Maine data, the question naturally arises as to how it compares with other studies made of time-ratio curves.[3] In the articles cited in the

[3] *The effect of travel time and distance on freeway usage*, by Darel L. Trueblood. PUBLIC ROADS, vol. 26, No. 12, Feb. 1952; also *Pennsylvania Turnpike traffic analysis*, by Daniel O'Flaherty. Pages 203–223 of this issue.

Figure 5.—Percentage of passenger cars using the Maine Turnpike in relation to the time ratio.

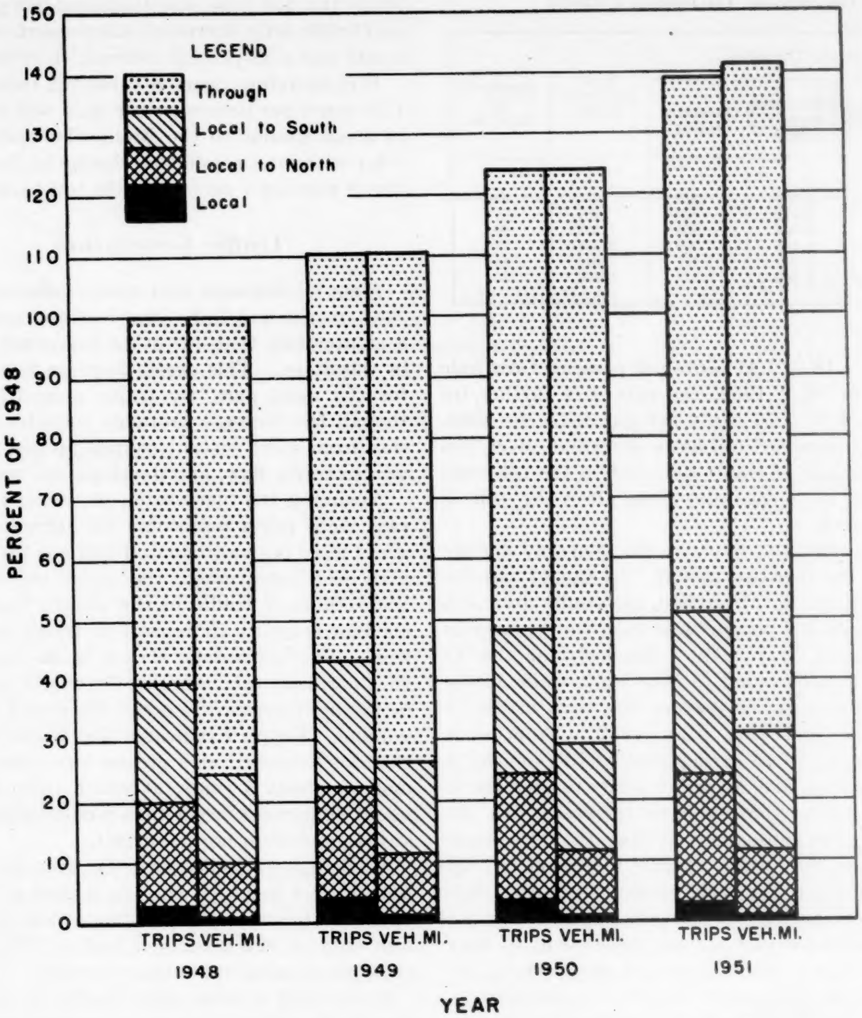


Figure 6.—Through and local passenger-car trips and vehicle-miles of travel on the Maine Turnpike for years 1949–51, as compared with 1948.

for the curve rotation is probably the effect of distance. The trips on the Pennsylvania Turnpike will average substantially longer than trips on the Maine Turnpike. Therefore, for equal time ratios other than 1.0, the time saved or lost would be much greater for the Pennsylvania than for the Maine Turnpike, tending to increase the attractiveness of the longer turnpike where the ratio is less than 1.0 and to decrease it where the ratio is greater than one.

A study of the rotation of the two curves indicates a number of features that should be kept in mind as further data become available.

1. The magnitude of time saved has an effect on the percentage diversion. At a constant time ratio, the greater the time saved the greater the diversion.

2. The magnitude of time lost also has an an effect on the percentage diversion. At a constant time ratio, the greater the time lost the less the diversion.

3. While the magnitude of time saved and time lost affects the diversion, the effect is less than that of time ratio. Thus, it is better to modify the time-ratio curves by considering the minutes saved or lost, than it would be to modify minutes saved or lost curves by time ratio.

4. The fact that the diversion is the same for a time ratio of 1.0 on both the Maine and Pennsylvania Turnpikes suggests that time ratio is a more vital factor than distance in traffic diversion, considering the fact that at this time ratio, the adverse distance would, on the average, be greater for the longer turnpike.

5. The Maine and Pennsylvania Turnpikes approximate the minimum and maximum length of turnpikes in the United States. Most turnpikes will fall into categories somewhere between these extremes.

footnote, it is found that the curves show greater diversion to the limited-access facilities. The Shirley Freeway curve (Shirley Memorial Highway in Virginia) if applied to the Maine data would result in 38 percent greater diversion to the turnpike than actually exists, illustrating primarily the greater attraction of traffic to a free road, though other factors are involved such as more points of access on the Shirley Highway, and the urban characteristics of the area through which the freeway passes as compared to the rural characteristics of the Maine Turnpike area.

Similarly the Pennsylvania Turnpike curve, though for a toll road, indicates an 18 percent greater diversion to the Maine Turnpike. It is noted, however, that the Maine and Pennsylvania curves have a striking similarity. Each of the curves show a diversion of about 18 percent of the traffic when the time ratio is 1.0. For higher time ratios, the Maine Turnpike curve indicates greater diversion than the Pennsylvania Turnpike curve and for lower time ratios, the Maine curve indicates less diversion than the Pennsylvania curve. Thus if the Maine curve is rotated about the point of 1.0 time ratio, it will practically coincide with the Pennsylvania curve. The reason

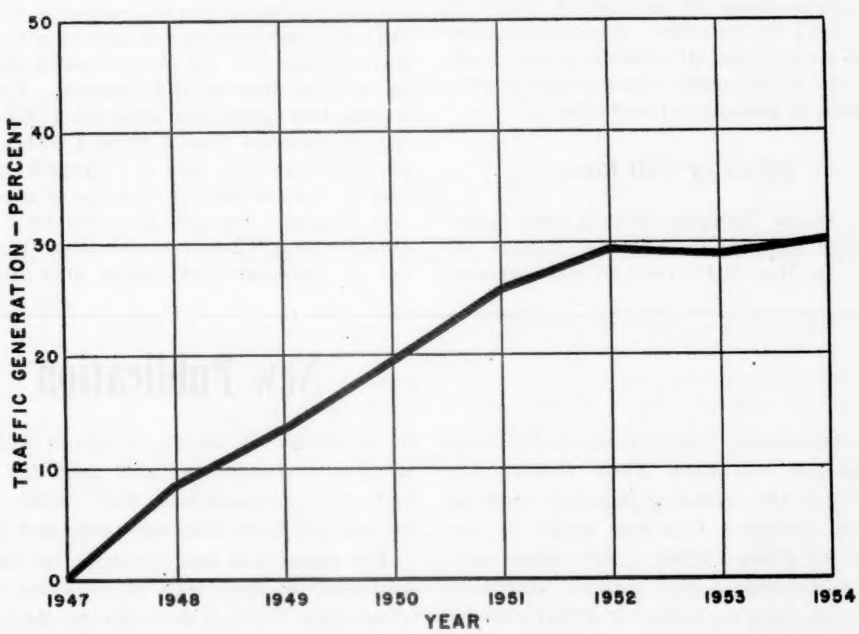


Figure 7.—Percentage of traffic generated in the Maine Turnpike corridor, 1947–54.

Table 5.—Traffic increase on U. S. 1 and the Maine Turnpike, 1948–54

Year	U. S. 1			Maine Turnpike			Total generated traffic	Percent generated on turnpike
	Actual count	Estimated normal increase	Generated traffic	Actual count	Estimated normal increase	Generated traffic		
1948	4, 194	--------	--------	3, 321	--------	--------	--------	--------
1949	4, 577	4, 433	144	3, 719	3, 510	209	353	59
1950	5, 033	4, 701	332	4, 252	3, 723	529	861	61
1951	5, 551	4, 982	569	4, 809	3, 945	864	1, 433	60
1952	6, 039	5, 234	805	5. 144	4, 145	999	1, 804	55
1953	6, 222	5, 477	745	5, 438	4, 337	1, 101	1, 846	60
1954	6, 229	5, 532	697	5, 653	4, 380	1, 273	1, 970	65

Types of Trips Made on the Turnpike

Traffic using the Maine Turnpike in the years 1948 through 1951 was divided into four groups as follows:

Through trips.—Trips that were made between the two terminal interchanges.

Local south trips.—Trips made between an intermediate interchange and the south terminal interchange.

Local north trips.—Trips made between an intermediate interchange and the north terminal interchange.

Local trips.—Trips made between two intermediate interchanges.

Figure 6 shows the relative number of trips in each category and the contribution of each type of trip to the total vehicle-miles traveled on the turnpike. The total trips and vehicle-miles of travel in 1948 are shown as 100 percent, and the quantities in the succeeding years are related to the 1948 base year. It can be seen that through trips are not only the most frequent but contribute more than 75 percent of the total traffic in each of the 4 years.

The usefulness of figure 6 is primarily in determining the number of interview lines that would be required in estimating traffic on a facility comparable to the Maine Turnpike.

Interview lines at the north and south ends intercepted about 99 percent of the total traffic using the turnpike. A south line alone would account for 90 percent of the traffic while one at the north alone, would account for about 85 percent of the traffic.

Effect of Toll Rate

The Maine Turnpike offers a good opportunity to measure the effect of various toll rates. In May 1949, the toll was increased from 1.18 to 1.41 cents per passenger-car mile and in May 1952, the rate was further increased to 1.76 cents per passenger-car mile. If the increased toll has a deterrent effect, the percentage of traffic diverted to the toll road should be measurably less after the toll is increased.

Actually, the diversion changed only slightly with the increase in toll. In the 11 months subsequent to May 1949, the traffic diversion was only 0.9 percent less than the 11 months preceding May 1949. Similarly in the 11 months subsequent to May 1952, traffic diversion was only 1.9 percent less than in the 11 months preceding May 1952. From data appearing in an earlier part of this article, it was shown that diversion tends to increase as the total corridor volume increases. In the 11 months subsequent to May 1949, the average corridor traffic volume increased by 675 vehicles per day which corresponds to a 0.5-percent increase in diversion. Similarly the increased corridor volume subsequent to May 1952, was 1,150 vehicles per day corresponding to an 0.8-percent increase in diversion.

It, therefore, seems reasonable to assume that increasing the toll rate from 1.18 to 1.41 cents per passenger-car mile had a total effect of losing the 0.5 percent anticipated increase plus the 0.9 percent actual decrease for a total decrease of 1.4 percent in diversion of passenger cars. Similarly the increase in tolls from 1.41 to 1.76 cents per passenger-car mile had the effect of losing the 0.8 percent anticipated increase plus the 1.9 percent actual decrease or the total decrease of 2.7 percent. Combining the two figures, the total effect of increasing the toll rate from 1.18 to 1.76 cents per passenger-car mile was a 4.1-percent reduction in the turnpike percentage of passenger cars passing through the corridor, which amounts to an 8.2-percent decrease in the number of passenger cars using the turnpike. Since the toll rate was increased 50 percent and traffic only decreased 8.2 percent, the net result was a 38-percent increase in revenue.

It is, therefore, apparent that toll rates up to 1.76 cents per passenger-car mile will be paid in areas similar to the Maine Turnpike corridor without a significant change in the number of passenger cars using the toll road.

Traffic Generation

Figure 2 indicates that total traffic on both the turnpike and U. S. 1 has been increasing at a greater rate than for other important roads in the State. This excess increase is caused, for the most part, by traffic generation although the increase probably includes diversion from more distant routes, normal variation in traffic flow, and development traffic.

Assuming the increase on the other important rural roads represents the increase that could have been anticipated had not the turnpike been constructed, the excess increase in the volume of traffic in the Maine Turnpike corridor is shown in figure 7 as traffic generation. The percentage shown is the amount that normally increasing traffic would have to be further increased to equal the actual traffic volume. Figure 7 indicates that traffic in the corridor increased at a greater rate than normal for about 5 years, at which time it was about 30 percent larger than would have been anticipated from normal growth.

While figure 7 indicates traffic generation on both U. S. 1 and the turnpike, it does not provide any information showing which facility was used by the generated traffic. This can be approximated in another manner.

If the 1948 average daily traffic on U. S. 1 and the turnpike is increased at the same rate as other important roads in Maine, it will be found that the computed traffic is not as large as the actual traffic as shown in table 5.

From the table it can be seen that about 60 percent of the traffic generated since 1948 is attracted to the turnpike and about 40 percent to U. S. 1. It is of interest to note that U. S. 1 continued to increase at a rate greater than normal until 1953, after which it increased at a rate less than normal. The average daily traffic on U. S. 1 in 1953 and 1954 was practically constant at about 6,225 vehicles, which is approximately 1,900 vehicles per day per 10-foot lane—nearly the same as in 1947. This observation suggests that U. S. 1 has again reached a point of congestion where traffic seeks to avoid it.

New Publication

A recent report, *The Financing of Highways by Counties and Local Rural Governments, 1942–51*, is the second publication resulting from an extensive long-term study by the Bureau of Public Roads. The report presents a discussion, and detailed statistical data, concerning the financing of highways by the county and local rural governments during the 10-year period. Included is information for each year, by States, on county and local receipts, expenditures, and debt for rural highways. Comparisons with earlier years are included in the summary tables and charts.

The report was made possible by the collection of the basic data through the efforts of the State highway departments, the county and local governments, and the field offices of the Bureau of Public Roads. The analysis and presentation were the work of the Financial and Administrative Research Branch, Bureau of Public Roads.

This publication is a sequel to the first study report, *The Financing of Highways by Counties and Local Rural Governments, 1931–41*. The present report is available from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., at 75 cents a copy.

U. S. GOVERNMENT PRINTING OFFICE: 1955

A list of the more important articles in PUBLIC ROADS may be obtained upon request addressed to Bureau of Public Roads, Washington 25, D. C.

PUBLICATIONS
of the Bureau of Public Roads

The following publications are sold by the Superintendent of Documents, Government Printing Office, Washington 25, D. C. Orders should be sent direct to the Superintendent of Documents. Prepayment is required.

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Work of the Public Roads Administration:
1941, 15 cents. 1948, 20 cents.
1942, 10 cents. 1949, 25 cents.

Public Roads Administration Annual Reports:
1943; 1944; 1945; 1946; 1947.
(Free from Bureau of Public Roads)

Annual Reports of the Bureau of Public Roads:
1950, 25 cents. 1952, 25 cents. 1954 (out of print).
1951, 35 cents. 1953, 25 cents.

PUBLICATIONS

Bibliography of Highway Planning Reports (1950). 30 cents.
Braking Performance of Motor Vehicles (1954). 55 cents.
Construction of Private Driveways, No. 272MP (1937). 15 cents.
Criteria for Prestressed Concrete Bridges (1954). 15 cents.
Design Capacity Charts for Signalized Street and Highway Intersections (reprint from PUBLIC ROADS, Feb. 1951). 25 cents.
Electrical Equipment on Movable Bridges, No. 265T (1931). 40 cents.
Factual Discussion of Motortruck Operation, Regulation, and Taxation (1951). 30 cents.
Federal Legislation and Regulations Relating to Highway Construction (1948). Out of print.
Financing of Highways by Counties and Local Rural Governments: 1931–41, 45 cents. 1942–51, 75 cents.
Highway Bond Calculations (1936). 10 cents.
Highway Bridge Location No. 1486D (1927). 15 cents.
Highway Capacity Manual (1950). $1.00.
Highway Needs of the National Defense, House Document No. 249 (1949). 50 cents.
Highway Practice in the United States of America (1949). 75 cents.
Highway Statistics (annual):
1945 (out of print). 1948, 65 cents. 1951, 60 cents.
1946, 50 cents. 1949, 55 cents. 1952, 75 cents.
1947, 45 cents. 1950 (out of print). 1953, $1.00.
Highway Statistics, Summary to 1945. 40 cents.
Highways in the United States, *nontechnical* (1954). 20 cents.
Highways of History (1939). 25 cents.
Identification of Rock Types (1950). Out of print.
Interregional Highways, House Document No. 379 (1944). 75 cents.
Legal Aspects of Controlling Highway Access (1945). 15 cents.
Local Rural Road Problem (1950). 20 cents.
Manual on Uniform Traffic Control Devices for Streets and Highways (1948) (*including 1954 revisions supplement*). $1.00.
Revisions to the Manual on Uniform Traffic Control Devices for Streets and Highways (1954). *Separate*, 15 cents.
Mathematical Theory of Vibration in Suspension Bridges (1950) $1.25.
Model Traffic Ordinance (revised 1953). 20 cents.

PUBLICATIONS (Continued)

Needs of the Highway Systems, 1955–84, House Document No. 120 (1955). 15 cents.
Principles of Highway Construction as Applied to Airports, Flight Strips, and Other Landing Areas for Aircraft (1943). $2.00.
Progress and Feasibility of Toll Roads and Their Relation to the Federal-Aid Program, House Document No. 139 (1955). 15 cents.
Public Control of Highway Access and Roadside Development (1947). 35 cents.
Public Land Acquisition for Highway Purposes (1943). 10 cents.
Public Utility Relocation Incident to Highway Improvement, House Document No. 127 (1955). 25 cents.
Results of Physical Tests of Road-Building Aggregate (1953). $1.00.
Roadside Improvement, No. 191MP (1934). 10 cents.
Selected Bibliography on Highway Finance (1951). 60 cents.
Specifications for Construction of Roads and Bridges in National Forests and National Parks, FP–41 (1948). $1.50.
Standard Plans for Highway Bridge Superstructures (1953). $1.25.
Taxation of Motor Vehicles in 1932. 35 cents.
Tire Wear and Tire Failures on Various Road Surfaces (1943). 10 cents.
Transition Curves for Highways (1940). $1.75.

MAPS

State Transportation Map series (available for 39 States). Uniform sheets 26 by 36 inches, scale 1 inch equals 4 miles. Shows in colors Federal-aid and State highways with surface types, principal connecting roads, railroads, airports, waterways, National and State forests, parks, and other reservations. Prices and number of sheets for each State vary—see Superintendent of Documents price list 53.
United States System of Numbered Highways together with the Federal-Aid Highway System (also shows in color National forests, parks, and other reservations). 5 by 7 feet (in 2 sheets), scale 1 inch equals 37 miles. $1.25.
United States System of Numbered Highways. 28 by 42 inches, scale 1 inch equals 78 miles. 20 cents.

Single copies of the following publications are available to highway engineers and administrators for official use, and may be obtained by those so qualified upon request addressed to the Bureau of Public Roads. They are not sold by the Superintendent of Documents.

Bibliography on Automobile Parking in the United States (1946).
Bibliography on Highway Lighting (1937).
Bibliography on Highway Safety (1938)
Bibliography on Land Acquisition for Public Roads (1947).
Bibliography on Roadside Control (1949).
Express Highways in the United States: a Bibliography (1945).
Indexes to PUBLIC ROADS, volumes 17–19 and 23.
Title Sheets for PUBLIC ROADS, volumes 24–27.

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STATUS OF FEDERAL-AID HIGHWAY PROGRAM

AS OF AUGUST 31, 1955

(Thousand Dollars)

STATE	UNPROGRAMMED BALANCES 1/	ACTIVE PROGRAM											
		PROGRAMMED ONLY			PLANS APPROVED, CONSTRUCTION NOT STARTED			CONSTRUCTION UNDER WAY			TOTAL		
		Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles
Alabama	$24,105	$11,897	$6,316	285.9	$5,210	$2,904	64.0	$44,376	$22,551	726.3	$61,483	$31,771	1,076.2
Arizona	12,337	2,850	2,165	65.6	1,347	947	40.9	10,690	7,812	185.0	14,887	10,924	291.5
Arkansas	19,656	6,372	3,414	248.4	5,037	2,701	68.2	21,702	11,040	534.7	33,111	17,155	851.3
California	27,936	45,874	25,117	262.2	8,061	4,625	8.2	133,431	65,777	319.0	187,366	95,519	589.4
Colorado	20,814	8,948	4,997	182.4	1,888	1,202	18.4	19,577	10,523	188.6	30,413	16,722	389.4
Connecticut	23,164	1,140	570	6.0	506	250	.9	9,309	4,602	12.3	10,955	5,422	19.2
Delaware	6,951	2,546	1,288	15.8	400	207	13.0	8,106	4,395	23.1	11,052	5,890	51.9
Florida	18,338	20,742	10,773	345.0	10,242	5,158	72.7	24,782	12,557	280.3	55,766	28,488	698.0
Georgia	30,255	19,113	9,619	366.3	9,364	4,279	67.5	44,062	20,684	764.4	72,539	34,582	1,198.2
Idaho	10,696	4,674	2,999	80.3	4,136	2,756	66.0	14,512	9,218	239.6	23,322	14,973	385.9
Illinois	35,589	46,064	26,117	430.9	15,156	7,798	37.4	91,817	48,711	728.4	153,037	82,626	1,196.7
Indiana	33,117	23,955	12,945	112.6	11,241	5,753	66.4	42,772	22,615	137.1	77,968	41,313	316.1
Iowa	22,000	14,990	8,338	575.7	5,854	3,090	96.0	28,587	15,675	1,079.3	49,431	27,103	1,751.0
Kansas	21,423	9,826	4,922	768.4	6,017	3,222	99.2	23,662	11,877	1,002.8	39,505	20,021	1,870.4
Kentucky	18,442	12,429	6,732	102.3	2,961	1,763	32.7	40,354	20,504	646.2	55,744	28,999	781.2
Louisiana	18,402	9,962	4,981	74.9	6,346	3,173	91.5	42,700	20,226	461.8	59,008	28,380	628.2
Maine	8,689	8,821	4,707	71.1	776	390	5.6	13,279	6,805	116.9	22,876	11,902	193.6
Maryland	14,602	21,011	11,036	83.9	4,944	2,274	15.6	12,540	6,668	81.6	38,495	19,978	181.1
Massachusetts	27,549	9,950	4,965	25.9	3,686	1,831	6.6	43,917	20,442	41.3	57,553	27,238	73.8
Michigan	31,143	46,415	24,115	729.3	14,808	7,724	102.7	46,720	23,468	434.5	107,943	55,307	1,266.5
Minnesota	23,102	9,120	4,690	441.1	9,767	5,330	409.0	36,324	18,930	1,232.5	55,211	28,950	2,082.6
Mississippi	16,533	8,238	4,030	319.0	6,772	3,778	110.2	30,240	15,380	775.0	45,250	23,188	1,204.2
Missouri	27,096	23,103	12,257	1,035.0	3,508	1,887	5.5	79,270	41,175	1,324.1	105,881	55,319	2,364.6
Montana	21,295	9,909	6,179	210.0	6,157	3,560	138.8	23,408	14,817	419.0	39,474	24,556	767.8
Nebraska	19,146	20,499	10,657	951.1	6,025	2,731	64.9	32,694	17,958	856.9	59,218	31,346	1,872.9
Nevada	15,719	2,911	2,473	78.3	781	650	21.0	7,951	6,666	149.2	11,643	9,789	248.5
New Hampshire	8,003	1,940	970	12.7	997	498	6.1	6,572	3,374	41.2	9,509	4,842	60.0
New Jersey	25,845	14,086	6,586	57.7	8,097	4,026	17.4	28,648	13,258	59.3	50,831	23,870	134.4
New Mexico	13,876	3,328	2,106	57.8	3,978	2,583	78.2	9,545	6,105	199.2	16,851	10,794	335.2
New York	82,983	19,697	10,280	46.6	34,745	16,803	78.7	226,876	105,958	317.3	281,318	133,041	442.6
North Carolina	26,501	18,281	9,040	305.4	5,370	2,624	84.7	43,334	21,419	651.9	66,985	33,083	1,042.0
North Dakota	13,132	5,494	2,784	888.8	7,078	3,548	699.0	12,112	6,088	609.8	24,684	12,420	2,197.6
Ohio	43,949	52,607	26,404	163.6	10,889	5,350	23.4	60,735	29,005	107.2	124,231	60,759	294.2
Oklahoma	25,849	12,720	6,843	274.3	14,405	7,333	166.9	27,694	14,518	387.6	54,819	28,694	828.8
Oregon	13,611	9,127	5,458	113.7	1,934	1,156	6.6	16,741	10,341	237.1	27,802	16,955	357.4
Pennsylvania	46,777	49,629	24,567	77.1	25,981	13,307	63.9	93,190	46,331	254.8	168,800	84,205	395.8
Rhode Island	7,392	3,744	1,872	10.7	3,161	1,580	2.4	11,458	5,742	36.9	18,363	9,194	50.0
South Carolina	16,672	12,448	6,673	360.2	5,005	2,686	23.3	18,563	9,801	344.7	36,016	19,160	728.2
South Dakota	12,947	13,102	7,546	641.7	3,527	2,055	138.6	9,892	5,716	477.8	26,521	15,317	1,258.1
Tennessee	28,805	15,188	7,552	260.9	6,650	3,325	64.4	36,456	16,512	442.3	58,294	27,389	767.6
Texas	58,289	19,979	10,388	423.8	22,238	12,109	215.7	81,606	43,118	1,219.9	123,823	65,615	1,859.4
Utah	9,428	4,759	3,574	79.0	2,258	1,645	12.5	12,208	9,265	234.2	19,225	14,484	325.7
Vermont	6,504	1,820	914	17.9	103	53	-.1	8,761	4,584	83.8	10,684	5,551	101.8
Virginia	25,501	12,940	6,652	220.6	5,617	2,631	67.7	23,732	11,725	299.7	42,289	21,008	588.0
Washington	16,499	17,441	9,522	175.2	3,262	1,937	62.1	21,708	11,531	137.8	42,411	22,990	375.1
West Virginia	18,853	10,067	5,140	46.8	3,824	1,905	28.0	17,579	8,840	78.9	31,470	15,885	153.7
Wisconsin	26,279	10,801	5,258	174.6	5,374	2,677	29.0	44,851	22,463	586.9	61,026	30,398	790.5
Wyoming	8,979	3,825	2,465	66.0	991	640	35.3	15,536	10,037	322.3	20,352	13,142	423.6
Hawaii	6,070	1,355	678	2.7	3,970	1,960	4.2	4,247	1,851	10.2	9,572	4,489	17.1
District of Columbia	10,498	4,977	2,489	6.6	317	158	.6	12,198	5,755	3.5	17,492	8,402	10.7
Puerto Rico	13,226	2,633	1,272	15.3	1,790	836	3.4	16,074	7,311	59.1	20,497	9,419	77.8
TOTAL	1,114,567	723,347	383,435	12,367.1	332,551	173,408	3,635.1	1,787,098	911,724	19,963.3	2,842,996	1,468,567	35,965.5

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1/ Includes 1957 apportionment effective August 9, 1955.

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